DOCTOR OF PHILOSOPHY

A multi-dimensional case for whether cardiorespiratory fitness testing of children should be implemented in primary schools in England

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By

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PhD

December 2019

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A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

Certificate of Ethical Approval

Applicant:

Samuel Tuvey

Project Title:

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This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

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PhD Declaration

The work submitted within this thesis has been undertaken during the period of my registration. I declare that this work is my own, conducted by myself with assistance where acknowledged.

I would like to acknowledge that Premier Education staff undertook the majority of the testing throughout the project. I was responsible for training the staff, liasing with the schools, and completing testing when Premier Education staff were unavailable. Further details of my role in the data collection can be found in the General Methods (Page 72-73).

Dedication

I wish to dedicate this thesis to my amazing fiancée, Steph for her never-ending support, even when it seemed as though I was determined to make a career out of being a student.

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Abstract

Introduction

The measurement of field-based cardiorespiratory fitness (CRF) has been identified as a feasible way to study the link between physical activity (PA) and health in children and adolescents at a population level (Lang et al., 2018a). Indeed, a former Chief Medical Officer for England called for the measurement of CRF as a surveillance tool almost a decade ago, yet no initiative has been put in place (Department of Health, 2010). Therefore, the overarching aim of this thesis was to determine whether there is a case for CRF testing of children in primary schools in England.

Methods

Following institutional ethical approval, the following participants were recruited; children aged 8-11 years from 17 primary schools in the London boroughs of Camden and Islington; children aged 9-11 years from nine elementary schools in Birmingham, Alabama and Oakland, California in the US; and seven teachers from the primary schools in the London boroughs of Camden and Islington. CRF was measured by the 20m Multistage Shuttle Run (20mMSR) as part of an initiative called the My Personal Best Challenge (MPBC). Height and weight were also obtained to calculate body mass index (BMI). Testing was completed by trained coaching staff from Premier Education during a Physical Education (PE) lesson.

Results

Study 1 involved performing a systematic review, meta-analysis and meta-regression to investigate whether changes in CRF, as a result of a PA intervention, had a significant impact on executive function or academic performance.

Key Findings from Study 1: PA interventions can improve CRF in children and adolescents (effect size (ES) = 0.24 [95% confidence interval (CI) = 0.09, 0.40]), yet do not impact executive function (ES = 0.14 [95% CI = -0.12, 0.41]) or academic performance (ES = 0.11 [95% CI = -0.16, 0.38]). Furthermore, the improvements in CRF produced by PA interventions are not associated with changes in executive function or academic performance, including no negative effect on either executive function or academic performance. Given that most of the PA interventions included in the meta-analysis took place in time allotted for other curricular activities, this finding is particularly noteworthy given the health benefits associated with improving CRF.

Study 2 aimed to compare the CRF of children who took part in the MPBC from primary schools in London with other studies in English, as well as to provide an international comparison between children who completed the MPBC in England with a convenience sample of children from the US.

Key Findings from Study 2: The current data on children's CRF levels in England is limited, with a lack of raw data available, difference in reporting methods, and data restricted to certain regions. However, comparison of group statistics found that children in the MPBC cohort from London had significantly lower CRF than boys and girls from the East of England ($p < 0.001$) and boys from Liverpool ($p < 0.001$). Study 2 also demonstrated how the implementation of a CRF testing programme could be completed

successfully in two different countries, with children from the MPBC London cohort having significantly higher CRF than children in the US cohort ($p < 0.001$).

Study 3 analysed the relationship between BMI with CRF, as well as applying a CRF cut-point to identify the percentage of children at an increased risk of cardiometabolic disease (CMD) in the different BMI weight categories.

Key Findings from Study 3: There was a significant, but weak, correlation between BMI and CRF in children in England ($r = -0.35$, $p < 0.001$). Furthermore, over half of children were at an increased risk of CMD due to low CRF (boys = 51.9%, girls = 55.2%), and approximately a quarter of children (boys = 24.1%, girls = 30.5%) were not being identified by current national measures based upon their BMI as they were "lean but unfit".

Study 4 explored how CRF levels of children in primary schools in England change over a 3-year period.

Key Findings from Study 4: Children's CRF levels improved during the final years of primary school after accounting for age, sex, socio-economic status, and BMI. Children who attended schools where a higher percentage of children were eligible for the Pupil Premium (PP) had significantly lower CRF (20mMSR z-scores mean difference = 0.64 [95% CI = 0.18, 1.1]), especially younger children, though this difference became less pronounced and disappeared by the end of primary school.

Study 5 provided a retrospective examination of the perceptions of primary school teachers, through semi-structured interviews on fitness testing of children and collected feedback on the MPBC programme.

Key Findings from Study 5: Teachers had positive perceptions overall about fitness testing in primary schools ($n = 6$) and believed that children enjoyed participating in fitness tests ($n = 5$).

Conclusions

Overall, this body of work has considered the case for whether CRF testing should be implemented in primary schools in England. This thesis has shown that CRF testing in schools can: be used as a tool to evaluate PA interventions, identify children at an increased risk of CMD, track the CRF of children over time and observe how changes in CRF may differ between groups, and make cohort comparisons nationally and internationally. Further, this thesis has demonstrated that teachers have positive perceptions of fitness testing in schools, and that children enjoy participating. As a result of the included studies, this thesis can conclude that there is indeed evidence for the implementation of standardised CRF testing and that it could help develop policy approaches to children's PA, and be used to evaluate their success.

Presentation of Results

Conference Presentations and Posters

Tuvey, S., Steele, J., Jimenez, A., Mann, S., Horton, E. (2019). Three-year surveillance of cardiorespiratory fitness in UK primary school children. *Presentation at ECSS Congress, Prague, Czech Republic.*

Tuvey, S., Horton, E., Steele, J., Mann, S., Liguori, G., Jimenez, A. (2018), In-situ testing of cardiorespiratory fitness and body mass index of schoolchildren in the UK. *Thematic Poster Presentation at the ACSM Annual Meeting, Minnesota, USA.*

Tuvey, S., Mann, S., Renshaw, D., Jimenez, A. (2017). Does cardiorespiratory fitness have an impact on academic performance? *Poster Presentation at Coventry University School of Health and Life Sciences Postgraduate Researcher Symposium, Coventry, UK.*

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List of Abbreviations

20mMSR	20m Multistage Shuttle Run
ACLS	Aerobics Centre Longitudinal Study
ACSM	American College of Sports Medicine
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AVENA	Alimentación y Valoración del Estado Nutricional de los Adolescentes Españoles
BMI	Body Mass Index
CI	Confidence Interval
CMD	Cardiometabolic Disease
CMO	Chief Medical Officer
CMR	Cardiometabolic Risk
CRF	Cardiorespiratory Fitness
CVD	Cardiovascular Disease
DBS	Disclosure and Barring Service
DHHS	Department of Health and Human Services
DXA	Dual Energy X-ray Absorptiometry
EOEHHS	East of England Healthy Hearts Study
EPHPP	Effective Public Health Practice Project
EYHS	European Youth Heart Study
HDL	High-Density Lipoproteins
HELENA	Healthy Lifestyle in Europe by Nutrition in Adolescence
HSE	Health Survey for England
IMD	Indices of Multiple Deprivation
IOTF	International Obesity Task Force
KPI	Knowledge Performance Indicator
LDL	Low-Density Lipoproteins
MET	Metabolic Equivalent
MPBC	My Personal Best Challenge
MRI	Magnetic Resonance Imagery
MVPA	Moderate to Vigorous Physical Activity
NCD	Non-Communicable Disease
NCMP	National Child Measurement Programme

NHANES	National Health and Nutrition Examination Survey
NHLBI	National Heart, Lung, and Blood Institute
NHS	National Health Service
NNYFS	NHANES National Youth Fitness Survey
OECD	Organisation for Economic Co-operation and Development
OFSTED	Office for Standards in Education
PA	Physical Activity
PACER	Progressive Aerobic Cardiovascular Endurance Run
PE	Physical Education
PP	Pupil Premium
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RCT	Randomised Controlled Trial
ROC	Receiver Operating Characteristic
SES	Socio-economic Status
UK	United Kingdom
US	United States
$\dot{V}O_{2max}$	Maximum Oxygen Uptake
$\dot{V}O_{2peak}$	Peak Oxygen Uptake
WHO	World Health Organization

CHAPTER 1.0 INTRODUCTION AND THESIS OUTLINE

1.1 Rationale and Background

In 2013 the World Health Organization (WHO) declared that non-communicable diseases (NCDs) were the leading cause of death worldwide (WHO, 2013). These diseases are non-transmissible amongst people and include cardiovascular disease (CVD), cancers, respiratory disorders and diabetes. The human, social and economic burden of NCDs impact people of all age-groups, regions, and countries. The long duration and slow progression of NCDs place financial strains upon societies, governments and health care programmes. Globally, 38 million (68%) of the world's 56 million deaths in 2012 were caused by NCDs, with CVD accounting for 17.9 million of these deaths, followed by cancer (9.0 million), respiratory diseases (3.9 million) and diabetes (1.6 million; WHO, 2013). These four groups represent over 80% of all premature NCD related deaths.

More than three quarters of deaths caused by NCDs occur in low- and middle-income countries (32 million; WHO, 2013). However, in developed countries NCDs remain as the leading cause of death. In the United Kingdom (UK), the WHO estimated that NCDs account for 89% of all deaths (WHO, 2018). Despite CVD mortality declining by 52% between 1990 and 2013 (Newton et al., 2015), there are still over 7 million people living with CVD in the UK, with the cost to the UK economy (including premature death, disability and informal costs) estimated at £19 billion each year (British Heart Foundation, 2019). Furthermore, life expectancy in England is increasing. In 1981, the average life expectancy was 71.1 years and 77.0 years for males and females respectively and increased to 79.5 years and 83.1 years, males and females respectively by 2017 (Office for National Statistics, 2018). This improvement in life expectancy has not been matched with improvements in healthy life expectancy, so there are now more people living longer with disabilities or comorbidities (Salomon et al., 2012). These trends look set to continue with life expectancy to increase to 81.1 years and 84.3 years for males and females respectively by 2023 (Public Health England, 2018).

Physical inactivity is one of the most significant behavioural factors that increases the risk of death by a NCD, and promotion of physical activity (PA) is considered a high priority (Blair, 2009; Trost, Blair & Khan, 2014; WHO, 2013). Caspersen, Powell, and Christenson (1985: 127) defined PA as the following:

1) Movement of the body produced by skeletal muscles.
2) Resulting energy expenditure that varies from low to high.
3) A positive correlation with physical fitness.

In September 2019, UK Chief Medical Officers (CMOs) published an update on the PA guidelines (Department of Health & Social Care, 2019). The new guidelines for children and young people aged 5-18 years were:

- Children and young people should engage in moderate to vigorous PA (MVPA) for an average of at least 60 minutes per day across the week. This can include all forms of activity such as physical education (PE), active travel, after-school activities, play and sports.
- Children and young people should engage in a variety of types and intensities of PA across the week to develop movement skills, muscular fitness, and bone strength.

- Children and young people should aim to minimise the amount of time spent being sedentary, and when physically possible should break up long periods of not moving with at least light PA.

The '*Active Lives Children and Young People Survey*' reported that of all children and adolescents aged 5-16 years, only 46.8% were meeting the CMOs' guideline of at least 60 minutes of MVPA per day (Sport England, 2019). In youth, the intensity and volume of PA has been associated with numerous physiological and psychological health benefits (Janssen & LeBlanc, 2010). Low levels of PA in childhood and adolescence have been associated with an increased risk of obesity, hypertension, cardiovascular risk factors, type II diabetes, and coronary heart disease (Mountjoy et al., 2011; Lee et al., 2012).

Many countries around the world now publish report cards on children and young people's PA (Tremblay et al., 2016). The country that had the highest overall PA grade in 2018 was Slovenia, who received an A- grade (Sember et al., 2018a), whereas England received a C- (Standage et al., 2018). The methods used to obtain England's grade of PA were nationally representative subjective assessments, or regionally representative objective assessments. A comparison of the report cards by Aubert et al. (2018) shows that this is common in most countries as only 5 of the 30 countries (Canada, Estonia, Finland, Portugal, and Slovenia) used a nationally representative objective assessment. This highlights the difficulty of conducting a study that is nationally representative using objective measurements of PA, even within high income countries. As an alternative, cardiorespiratory fitness (CRF) is a physical trait that is primarily determined by PA behaviours. CRF is defined as "the ability to deliver oxygen to the muscles and to utilise it to generate energy to support muscle activity during exercise" (Armstrong, Tomkinson & Ekelund, 2011). CRF has been described as representing a variable linking PA behaviours and health outcomes and reflects the capacity of the heart, lungs and muscles to support energy production during PA and exercise (Lang et al., 2018a). Although CRF is determined partially by genetics (30-50%), increasing habitual PA is the primary method of improving CRF (Lang et al., 2018a). Therefore, CRF can be considered a proximal outcome of PA levels.

Physical fitness is defined "as the ability of a person to perform physical activity (PA) and/or exercise and represents an integrated measure of all the functions and structures involved in the practice of PA or exercise" (Ortega et al., 2013: 461). The PA report cards provide a grade for physical fitness, with Slovenia receiving the highest grade of A- (Sember et al., 2018b), whilst England received a C- (Standage et al., 2018). A notable feature of Slovenia is that they have in place a national school-based surveillance system of physical fitness, called SLOfit, which targets the majority of children and youth aged 6-19 years (Strel et al., 1997). Surveillance systems, such as SLOfit, are especially important in guiding and evaluating health-promoting policies and interventions (Hall et al., 2012). SLOfit monitors trends in the youth population of Slovenia, after it observed a decrease in fitness and rise in obesity, the Slovenian government implemented a national health-orientated PA programme, which offered children an additional 2 hours of PA per week (Sember et al., 2018b). The percentage of children and youth now reaching the recommended guidelines is over 80%, which is an encouraging outcome.

Currently, the only national indicator of children's health status that is routinely assessed using an objective measurement in England is body mass index (BMI). BMI is calculated from a person's height and mass using the following calculation; BMI = $kg{\cdot}m^{-2}$. Due to children and adolescents growing and maturing at different rates, age- and sex-specific reference curves were developed by Cole et al. (1990) to identify those who are overweight or obese. For the purpose of this thesis, overweight and obesity is defined as the accumulation of excess body mass determined in children using age- and sex-specific cut-points as reported by Cole, Freeman and Preece (1995). Overweight is defined as a BMI at or above the 85th percentile and lower than the 95th percentile for children of the same age and sex (Cole et al., 2000). Obesity is defined as a BMI at or above the 95th percentile for children of the same age and sex (Cole et al., 2000). The National Child Measurement Programme (NCMP) measures the height and mass to calculate the BMI of nearly every child (95% of eligible children in 2018/19) in Reception (aged 4-5 years) and Year 6 (aged 10-11 years) at primary schools in England (National Health Service (NHS), 2019). In 2018/19, the NCMP found that 22.6% and 34.3% of children in Reception and Year 6 respectively were classified as being overweight or obese (NHS, 2019). This data is used to monitor children's health status at a population level in England and has been collected since 2006/07 (NHS, 2019). This type of data is also used to compare the prevalence of childhood obesity over time, between regions and local authorities, as well as between ethnicities and levels of deprivation (NHS, 2019).

Recently, several publications from the UK governing bodies have been released to try and address the situation facing children's health. These include '*Childhood Obesity – A Plan for Action*' (Department of Health & Social Care, 2016), '*Sporting Future: A New Strategy for an Active Nation*' (Department of Culture, Media & Sport, 2015) and '*Towards an Active Nation*' (Sport England, 2016).

'*Childhood Obesity – A Plan for Action*' is a UK government strategy aiming to reduce England's childhood obesity rate through a number of objectives (Department of Health & Social Care, 2016). Firstly, a key point of this strategy was the introduction of the soft drinks sugar levy, which targets sugar sweetened beverages only, rather than drinks that get their sugar content from fruit, vegetables or dairy. The sugar levy has been enforced since April 2018. The money from this levy is to be invested into programmes to reduce obesity in schoolchildren by doubling the PE and Sport Premium, and investing £10million in healthy breakfast clubs. Secondly, a key target of the strategy was to reduce the sugar content of nine categories of food that make the largest contributions to sugar intake in children's diets, including; breakfast cereals, yoghurts, biscuits, cakes, confectionary, pastries, puddings, ice cream, and sweet breads. All food and drinks sectors were challenged to reduce the sugar in their products by 20% by 2020, however this is voluntary and there was no mention of penalties or sanctions. Thirdly, the strategy described how the UK government want to increase the PA of children by asking schools to provide opportunities for at least 30 minutes of MVPA per day through active break times, PE, extra-curricular activities, active lessons, or other sport and PA events. This is only a request to schools, and if schools do decide to provide these opportunities, the sessions are not necessarily compulsory for children to participate in. Meanwhile, parents are challenged with responsibility for providing the remaining 30 minutes of PA for children to achieve the recommendation set in the PA guidelines. Data from the '*Active Lives Children and Young People Survey*' shows that 40% of children and young people are participating in at least 30 minutes of PA at school, whilst 57% are taking part in at least 30 minutes of PA outside of school (Sport England, 2019). However, a recent study found that fitness levels decrease over the school holiday period and that this decrease in fitness is amplified for children from more deprived backgrounds (Mann et al., 2019). Fourthly, the strategy is introducing a 'Healthy Rating Scheme' for schools. Unfortunately, this scheme is voluntary for schools to participate in and due to the scheme being considered by the Office for Standards in Education (OFSTED), underachieving schools may be less likely to participate. One of the key issues with this strategy plan is that no Knowledge Performance Indicators (KPIs) or targets had been set in the initial release in 2016. In the second chapter of this strategy released in 2018, the government set the target of halving the prevalence of childhood obesity by 2030 (Department of Health & Social Care, 2018). Since the release of the initial report in 2016 the prevalence of childhood obesity has remained steady. For children in Reception, 22.6% of children were classified as being overweight or obese in 2016/17 compared to 22.6% in 2018/19 (NHS, 2019). The prevalence of children in Year 6 classified as being overweight or obese also remained at the same level, from 34.3% in 2016/17 to 34.3% in 2018/19 (NHS, 2019).

'*Sporting Future: A New Strategy for an Active Nation*' and '*Towards an Active Nation*' shared a number of similar KPIs (Department of Culture, Media & Sport, 2015; Sport England, 2016). These KPIs included expanding the remit of the population that Sport England would work with, from children aged 14 years and older to children aged 5 years and older, as well as to focus on inactivity and under-represented groups, among other objectives. Sport England are also responsible for administering the '*Active Lives Children and Young People Survey*' and reported that 46.8% of all children and young people were meeting the recommended PA levels in 2018/19 (Sport England, 2019). Self-report questionnaires such as the '*Active Lives Children and Young People Survey*' are commonly used to estimate levels of PA in children and young people because they are cost-effective, non-invasive, and can be self-administered (Pols, Peeters, Kemper & Grobbee, 1998; Dishman, Washburn & Schoeller, 2001). However, measures that are self-reported only provide a subjective estimate of PA and can be influenced by reporting bias, impacting their reliability and validity (Aggio et al. 2016; Chinapaw et al., 2010;

Martinez-Gomez et al., 2009). Reliance upon subjective measures as an indicator of PA levels in youth is cause for further concern as research suggests that children and adolescents are less likely to be able to define and classify the intensity of PA they have undertaken (Crossley et al., 2019; Pearce, Harrell & McMurray, 2008). Objective measures of PA can provide more accurate estimates of overall PA levels, but these methods are not always feasible and there are challenges related to cost and time for data collection and analysis (Hallal, Matsudo & Farias, 2012a). Currently, there is no national measurement programme which includes objective indicators of PA in England. The three aforementioned strategies all describe their aims to improve PA levels of children and young people. However, BMI measures children's weight status, and there are limitations with using subjective measures to estimate PA, especially in a youth population. Assessing CRF could therefore be considered as an alternative objective measurement, as changes in CRF levels are primarily determined by changes in PA.

The school setting has been viewed as a promising location for CRF testing of children and youth on a national scale for many years (Pate, 1989). Efforts to introduce school-based surveillance of CRF could also be considered a population-based intervention (Lang et al., 2018a). Routinely measuring CRF would allow it to gain more attention, similar to how the standardised testing of certain academic subjects places more importance on them over others. Yet, only a few countries have implemented CRF surveillance in schools on a national scale; including Hungary (Csányi et al., 2015), South Korea (Tomkinson et al., 2007), Japan (Macfarlane & Tomkinson, 2007), China (Macfarlane & Tomkinson, 2007), Slovenia (Jurak et al., 2019), and certain states in the United States (Welk et al., 2016). Two reports published by ukactive in recent years, 'Generation Inactive' and 'Generation Inactive 2' (ukactive, 2017; ukactive, 2018), further highlight the increased focus on improving children's PA levels and reducing their sedentary time. A key recommendation from both reports was that there should be routine and systematic measurement of children's CRF. This builds on a statement from the former CMO for England who said *"the introduction of a standardised school-based fitness assessment in England may have multiple benefits that extend beyond the benefits for the individual"* (Department of Health, 2010).

PE is compulsory at all key stages in local authority-maintained schools in England, and the National Curriculum programmes of study outline what should be taught at each Key Stage. The stated aims of the National Curriculum for PE are to ensure that all pupils:

- develop competence to excel in a broad range of physical activities
- are physically active for sustained periods of time
- engage in competitive sports and activities
- lead healthy, active lives.

(Department of Education, 2013)

During Key Stage 2, where children are aged 7-11 years old, one of the National Curriculum programmes of study for PE is that pupils should be taught to compare their performances with previous ones and demonstrate improvement to achieve their personal best (Department of Education, 2013). This programme of study could therefore include children taking part in a fitness test and being taught to monitor their performances and strive for personal improvement. However, the validity and reliability of field-based fitness tests being used with youth populations has previously been questioned as other factors may impact their performance, such as; heredity, maturation, motivation, environment/test conditions, lifestyle, test protocol, and intellectual and mechanical skill at taking the test (Armstrong & Welsman, 2019). Furthermore, Harris and Cale (2007) reported that a number of stakeholders, including teachers, had concerns about fitness testing in schools. Therefore, the need for qualitative feedback on any fitness test that is implemented in a youth population is also warranted to determine its acceptability.

The *Education Act 2002* prohibits the Secretary of State for Education from prescribing how much time should be spent on any curriculum subject (Foster & Roberts, 2019). Therefore, the additional pressure on schools to perform well in other curricular subjects that are routinely assessed by OFSTED, such as reading and mathematics, can lead to less time being allocated to subjects such as PE (Coe et al., 2006; Tsai et al., 2009; Arnold et al., 2016). Currently, OFSTED recommend that primary schools should spend at least 2 hours per week on core PE (OFSTED, 2013). However, a recent review by OFSTED found that only 69% of primary schools had 2 hours or more of PE timetabled each week and that some schools reported that time was being lost due to time spent changing and setting up the lessons (OFSTED, 2018). Recently, there has been a growing body of evidence suggesting that higher CRF levels are associated with better executive function and academic performance in children and adolescents (Santana et al., 2017; Donnelly et al., 2016). Therefore, it may be in schools' interests to allocate more time to improving the CRF of their pupils through physical activities, either curricular or extra-curricular, if this in turn improves their pupils' performance in other academic subjects that are routinely assessed by OFSTED.

1.2 Thesis Outline

To this end, the overarching aim of this thesis was to determine whether there is a case for CRF testing of primary school children to be adopted in England. The aims of this thesis were:

- Study 1: To determine if changes in CRF, as a result of a PA intervention, impacted executive function or academic performance in children and adolescents by performing a systematic review, meta-analysis, and meta-regression.
- Study 2: To complete a cohort comparison between with other studies that have measured CRF in England, and an international comparison between our English dataset with a convenience sample from the US.
- Study 3: To determine the proportion of children that were not being identified as "at risk" of cardiometabolic disease (CMD) by BMI cut-points compared to a previously determined cut-point in the 20mMSR.
- Study 4: To track the longitudinal changes in children's CRF levels across a three-year period and to examine the effects of socio-economic status (SES) on these trends.
- Study 5: To examine teachers' perceptions of fitness testing delivery in primary schools through semi-structured interviews.

CHAPTER 2.0 LITERATURE REVIEW

2.1 Overview of Fitness

Physical fitness includes cardiorespiratory, musculoskeletal, endocrinometabolic, psychoneuralogical and hematocirculatory functions (Ortega et al., 2013). Ortega et al. (2013) described how people with high physical fitness levels have high-quality and coordinated physiological responses to these functions, whilst people with poor physical fitness levels may have an impairment of one or more of these functions. The American College of Sports Medicine (ACSM) stated that physical fitness can be described in terms of skill- and health-related fitness (ACSM, 2010). Skill-related fitness is associated with motor skill performance or sport: the components of skill-related fitness include speed, agility, balance, coordination, power and reaction time (ACSM, 2010). As implied by the name, health-related fitness is an important component of overall health. ACSM (2010) stated that it is important to maintain a basic level of fitness throughout life to meet the demands of living and to promote health. Health-related fitness is associated with the following components: body composition, flexibility, cardiorespiratory fitness (CRF), and muscular strength and endurance (ACSM, 2010). Of these components, CRF has been found to be most strongly associated with health outcomes (Ruiz et al., 2009).

2.1.1 Cardiorespiratory Fitness

CRF refers to the ability of the circulatory, pulmonary and cardiac systems to pump blood, supply fuel and eliminate waste products throughout the body during exercise (Armstrong & Welsman, 1997). CRF can also be considered as a direct measure of a person's physiological status (Eisenmann, 2007). Genetics have a large influence on CRF, although it can also be affected by environmental factors (Hopkins et al., 2010). There are many terms for CRF that are used interchangeably in the literature but refer to the same concept, including cardiorespiratory endurance, cardiovascular endurance, cardiovascular fitness or aerobic fitness (Corbin et al., 2014). The term aerobic capacity is also often considered a synonym for CRF but it is important to understand the differences between the two terms. CRF reflects both health-related and functional fitness and is measured by field fitness tests. Aerobic capacity reflects the overall capacity of the cardiovascular and respiratory systems, but not necessarily functional fitness (Corbin et al., 2014). However, for consistency in this thesis the term CRF will be used.

2.1.1.1 Measurement of Children's Cardiorespiratory Fitness

In paediatric exercise science, the measurement of CRF is one of the most widely reported variables (Armstrong, Tomkinson & Ekelund, 2011; Tomkinson et al., 2019a). The maximum oxygen uptake ($\dot{V}O_{2max}$) has been described as the most important parameter of CRF (Ferrazza et al., 2009; Midgley & Carroll, 2009). Due to only 20-40% of children performing exercise to exhaustion displaying a plateau in their $\dot{V}O_2$ response to exercise, the term peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) is often adopted (Armstrong et al., 1995; Rowland, 1993). De Groot et al. (2009) defined $\dot{V}O_{2peak}$ as the highest oxygen uptake attained during a single progressive cardiopulmonary exercise test. Nearly all measures of CRF are objective for children and adolescents, with only one subjective measure, the International Fitness Scale (Ortega et al., 2011; Sánchez-López et al., 2015). The objective measures of CRF can be categorised as laboratory- or field-based tests (Tomkinson & Olds, 2008).

The criterion standard measure of CRF in youth is considered to be measuring $\dot{V}O_{2peak}$ through indirect calorimetry in a laboratory-based test (Lang et al., 2018a). Armstrong and Barker (2009) described how $\dot{V}O_{2peak}$ can be calculated in absolute terms ($L \cdot min^{-1}$), or relative terms ($ml \cdot kg^{-1} \cdot min^{-1}$) using either body mass or lean body mass. The results between the two methods can vary, although controlling for body mass appears to be preferred, as it has been found to be a better predictor of health (Buskirk & Taylor, 1957; Lloyd et al., 2009). However, a direct measurement of $\dot{V}O_{2peak}$ is often difficult to do with large populations and in school settings due to numerous costs and logistical challenges such as necessity for sophisticated instruments, qualified technicians and time constraints (Castro-Piñero et al., 2010).

Field-based tests provide a reasonable alternative since they are time efficient, low in cost and equipment requirements, and can be easily administered to a large number of people simultaneously (Castro-Piñero et al., 2010). However, limitations that have been cited in the past with children performing CRF field tests, included the appropriateness of maximal fitness tests for use with children, they only provide a crude measure of an individual’s fitness, and reliability and validity concerns for some fitness tests that stem from factors such as motivation (Harris & Cale, 2007). There are numerous field tests that have been used to measure CRF in youth populations, including variations of the following; walk/run distance tests, walk/run time tests, and the 20m Multistage Shuttle Run (20mMSR).

2.1.1.2 The 20m Multistage Shuttle Run

The 20mMSR is the most commonly used assessment of CRF worldwide. A comparison of the field-based CRF tests found that the 20mMSR had the highest reliability (r = 0.78-0.93) and highest criterion-related validity (r = 0.57-0.95) for children aged 8-18 years (Artero et al., 2011; Castro-Piñero et al., 2010). The 20mMSR was originally developed in the 1980s (Léger et al., 1984), and has been used to measure CRF in more than 50 countries (Lang et al., 2018b). The 20mMSR requires participants to run back and forth between two shuttles 20m apart in time with an audio signal (beep), with the pace increasing at set stages. There are several variations of the test, which differ by starting speed, time duration between stages and how much the pace increases between stages. Tomkinson et al. (2019a) recommended all studies should report the 20mMSR protocol that was adopted. These protocol variations are summarised below:

1) Léger et al.'s (Léger et al., 1984; Léger et al., 1988) original 1-minute protocol. Start speed 8.5 $km{\cdot}h^{-1}$. Increases by 0.5 $km{\cdot}h^{-1}$ each minute.
2) The Queen's University of Belfast protocol (Riddoch, 1990). Starts at 8.0 $km{\cdot}h^{-1}$ and increases by 0.5 $km{\cdot}h^{-1}$ each minute.
3) The protocol used by the Australian Coaching Council (Australian Sports Commission, 1999), British National Coaching Foundation (Brewer, Ramsbottom & Williams, 1988), Eurofit (Council of Europe, 1988), American Progressive Aerobic Cardiovascular Endurance Run (PACER) system (Cooper Institute for Aerobics Research, 1992), and others. Starts at 8.0 $km{\cdot}h^{-1}$, second stage is 9.0 $km{\cdot}h^{-1}$. Then increases by 0.5 $km{\cdot}h^{-1}$ each minute.

Tomkinson et al. (2003) highlighted in their review that in the past, authors often appeared to be unaware of the protocol variants, and frequently referred to the study by Léger and Lambert (1982) in their methods sections. The study by Léger and Lambert (1982) actually described the 20mMSR with 2-minute stages. Tomkinson et al. (2003) also described how the description of the 20mMSR did not match the reference and in other studies no indication was given. Table 2.1 shows the structure of each of the three 20mMSR protocols.

The main concern regarding the 20mMSR is that it does not provide a direct measurement of $\dot{V}O_{2peak}$ (Lang et al., 2018a). Performance in the 20mMSR is influenced by several different factors, including $\dot{V}O_{2peak}$ kinetics, running economy, fat mass, lactate threshold, anaerobic capacity, fractional usage of oxygen, and psychosocial factors such as motivation and pacing (Tomkinson & Olds, 2008; Lang et al., 2018a). This indicates that laboratory- and field-based tests may assess different aspects of CRF. This has led to the discussion among researchers about how the results from the 20mMSR should be reported, either raw values (shuttles, stages), or converted to $\dot{V}O_{2peak}$ using a prediction equation. To the best of our knowledge, there are five published $\dot{V}O_{2peak}$ prediction equations (Table 2.2).

Table 2. 1 Running speed ($km \cdot h^{-1}$) and number of shuttles for each stage of the 20m Multistage Shuttle Run according to three protocols

Stage no.	Protocol 1 (Léger et al., 1984; Léger et al., 1988)		Protocol 2 (Queen's University of Belfast)		Protocol 3 (Eurofit)	
	Speed ($km \cdot h^{-1}$)	No. of shuttles	Speed ($km \cdot h^{-1}$)	No. of shuttles	Speed ($km \cdot h^{-1}$)	No. of shuttles
1	8.5	7	8.0	7	8.0	7
2	9.0	8	8.5	7	9.0	8
3	9.5	8	9.0	8	9.5	8
4	10.0	8	9.5	8	10.0	8
5	10.5	9	10.0	8	10.5	9
6	11.0	9	10.5	9	11.0	9
7	11.5	10	11.0	9	11.5	10

Table 2. 2 20m Multistage Shuttle Run prediction equations to estimate $\dot{V}O_{2peak}$ in children and youth

Citation	Sample	Country	Equation to Estimate $\dot{V}O_{2peak}$
Léger et al. (1984)	188 boys and girls, aged 8-19 years	Canada	$\dot{V}O_{2peak} = 31.025 + 3.238 \cdot S - 3.248 \cdot A + 0.1536 \cdot S \cdot A$
Ruiz et al. (2008)	122 boys, 71 girls, aged 13-19 years	Spain	Artificial neural network equation available from: http://www.helenastudy.com/scientific.php
Mahar et al. (2006)	61 boys, 74 girls, aged 12-14 years	United States	$\dot{V}O_{2peak} = 47.438 + L \cdot 0.242 + G_1 \cdot 5.134 - W \cdot 0.197$
Matsuzaka et al. (2004)	62 boys, 70 girls, aged 8-17 years	Japan	$\dot{V}O_{2peak} = 25.9 - 2.21 \cdot G_2 - 0.449 \cdot A - 0.831 \cdot BMI + 4.12 \cdot S$
Barnett et al. (1993)	27 boys, 28 girls, aged 12-17 years	Hong Kong	$\dot{V}O_{2peak} = 25.8 - 6.6 \cdot G_2 - 0.2 \cdot W + 3.2 \cdot S$ $\dot{V}O_{2peak} = 24.4 - 5.0G_2 - 0.8 \cdot A + 3.4 \cdot S$

A = age (years); BMI = body mass index ($kg \cdot m^{-2}$); G_1 = sex (female = 0, male = 1); G_2 = sex (male = 0, female = 1); L = number of shuttles completed; S = end running speed ($km \cdot h^{-1}$); W = body mass (kg)

Tomkinson et al. (2019a) recommended that the 20mMSR results should be reported in multiple metrics (e.g. number of shuttles completed, half stages and running speed at the last completed stage/shuttle). Lang et al. (2018a) reported that the use of raw 20mMSR values (i.e. shuttles, stages, end running speed) provide the best estimate of CRF performance, and it is these values that have been used to calculate normative-referenced standards such as those derived by Tomkinson et al. (2017) and Sandercock et al. (2012). Normative-referenced standards allow for comparison against a reference population to determine how well children compare to their peers (Tomkinson et al., 2017). This approach is commonly used in Physical Education (PE) and has historically been used to track sports/athletic performances against centile bands to monitor whether changes in performance are better or worse than developmental changes (Tomkinson et al., 2019a). Tomkinson et al. (2019a) also recommended that normative-referenced standards could be used to facilitate comparisons within and between countries, as well monitor temporal trends in CRF. The primary limitation with normative-referenced standards are that they are not linked to a health outcome (Lang et al., 2018a). Another approach used to help interpret the 20mMSR are criterion-referenced standards. Health-related criterion-referenced standards are used primarily as a method by practitioners to identify children that are at an increased risk of diseases in the future and who may need an intervention (Lang et al., 2018a). The limitation with this approach is that 20mMSR raw performance scores cannot be used. This is due to the majority of criterion-referenced standards being developed using laboratory-based tests measuring $\dot{V}O_{2peak}$, resulting in the standards being reported as $ml \cdot kg^{-1} \cdot min^{-1}$ (Lang et al., 2018a). Therefore, the raw 20mMSR performance scores need to be converted in $\dot{V}O_{2peak}$ or the standards converted in the 20mMSR values. These two approaches to interpreting 20mMSR results have emerged as two separate ideologies (Lang et al., 2018a). However, Lang et al. (2018a) also described how these two approaches compliment each other and that both should be reported in population surveillance studies.

Previously, the 20mMSR has been described as appropriate for population-based surveillance projects for several reasons, including easily interpretable results, simple testing procedures, flexibility of testing environment, low cost, no need for specialist equipment and ability to test large groups simultaneously (Ruiz et al., 2009; Tomkinson & Olds, 2008; Lang et al., 2018a). The 20mMSR has been found to be the most valid and reliable field-based CRF test (Artero et al., 2011; Castro-Piñero et al., 2010). However, whilst validity and reliability are very important, the criterion of the scalability of a field-based test also needs to be considered if a CRF test is to have the potential to extend into a real-world setting. A recent review by Domone et al. (2016) investigated the scalability of field-based tests of CRF, and they found that the 20mMSR was the most scalable test in a school setting.

2.2 Cardiorespiratory Fitness Levels

A review by Armstrong, Tomkinson and Ekelund (2011) reported that gas-analysed $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) of ~5000 (exact *n* not reported) children and adolescents aged 8-18 years from 5 countries remained stable between 1962 and 1994. However, the stability of CRF levels found by Armstrong, Tomkinson and Ekelund (2011) during this period may not reflect more recent historical trends, and further a non-representative sample of volunteers, who possibly had an athletic predisposition, were used. Tomkinson et al. (2019b) reported a better representation of more recent trends of CRF at population level with ~1 million children and adolescents aged 9-17 years from 19 upper-middle income to high-income countries between 1981 and 2014. To calculate the $\dot{V}O_{2peak}$ and the percentage change, the end speed of the 20mMSR was used. The findings of Tomkinson et al. (2019b) show an overall decline in CRF in the 1980s of -2.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (95% Confidence Interval (CI) = -2.4, -2.0), and -1.6 $ml \cdot kg^{-1} \cdot min^{-1}$ (95% CI = -1.7, -1.5) in the 1990s, which agrees with previous reviews of temporal trends for these time periods (Tomkinson et al., 2003; Tomkinson & Olds, 2007). However, since the turn of the century the decline in CRF has decreased and nearly stabilised on an international scale (Tomkinson et al., 2019b), with a decline of -0.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (95% CI = -0.5, -0.3) in the 2000s, and a decline of -0.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (95% CI = -0.4, 0.0) in the 2010s. When compared across the different age-groups and between sexes this trend was consistent (Tomkinson et al., 2019b). Whilst these findings are promising on an international scale it is also important to look at the individual country data for England. Tomkinson et al. (2019b) had pooled studies from England, Wales, and Northern Ireland and reported the results from the UK. Interestingly, of the 19 countries included in the review by Tomkinson et al. (2019b), the UK was one of four countries that demonstrated a positive change in CRF before the year 2000, with a mean increase of 0.2 per decade (95% CI = 0.0, 0.4), which can also be interpreted as a 0.5% increase per decade (95% CI = 0.0, 1.0). However, a finding that should cause concern is that since the turn of the century the UK is now demonstrating a shift from an increase to a decline in CRF of -2.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (95% CI = -2.6, -2.2), or -5.2% per decade (95% CI = -5.6, -4.8).

There is a lack of population-level studies that track changes in CRF in children in England. Most studies that have collected data on children's CRF have taken place in Liverpool as part of the SportsLinx project (Taylor et al., 2004), which was run in partnership between Liverpool John Moore University and Liverpool City Council.

SportsLinx has collected data on body mass index (BMI), fitness, dietary habits and health of children aged 9-10 years since 1998. The project has been able to provide data and information to partners to inform service and interventions. SportsLinx has been able to offer a substantial amount of information on the health and fitness of children in Liverpool. SportsLinx has been able to track the secular trends of physical fitness and prevalence of overweight and obesity. A key difference between the methods used to calculate trends in the review by Tomkinson et al. (2019b) and the studies published as part of the SportsLinx project were that Tomkinson et al. (2019b) calculated $\dot{V}O_{2peak}$ from the end speed, and SportsLinx studies used the number of shuttles completed in the 20mMSR. For example, the study by Stratton et al. (2007) reports a 2.4% annual decline in 20mMSR performance (number of shuttles), whereas if the end speed is used there is a 0.8% decline. Furthermore, as previously described estimated $\dot{V}O_{2peak}$ is calculated using the end speed of the 20mMSR, not by the number of shuttles. This needs to be considered when the following studies' annual changes in CRF are described. A study by Boddy et al. (2012a) as part of the SportsLinx project found that there was a decline from 47 shuttles and 34 shuttles for boys and girls, respectively, in 1998/1999 to 42 shuttles and 29 shuttles for boys and girls, respectively, in 2009/2010. This represents an annual decline in CRF (number of shuttles completed in 20mMSR) between 1998/1999 and 2009/2010 of -1.34% and -2.29% for boys and girls, respectively, whilst controlling for age and BMI (Boddy et al., 2012a). When converted to end speed, there was only a small decrease from 11.0 $km\cdot h^{-1}$ to 10.5 $km\cdot h^{-1}$ for boys, and 10.0 $km\cdot h^{-1}$ to 9.5 $km\cdot h^{-1}$ for girls. This shows an annual decline of 0.4% for both boys and girls. Boddy et al. (2012a) measured the CRF of 27,942 children in total (lowest annual sample of 983 in 2002/2003, highest annual sample of 3,310 in 2006/2007). Two other studies that were a part of the

SportsLinx project measured the changes in BMI and prevalence of obesity between 2000 and 2008 (Stratton et al., 2007; Boddy, Hackett & Stratton, 2010). Stratton et al. (2007) found that there was an increase in BMI and the prevalence of obesity between 1998 to 2004 (Stratton et al., 2007), whilst Boddy, Hackett and Stratton (2010) found that there was no change in BMI between 2005 to 2008 and the prevalence of obesity had plateaued, independent of CRF and deprivation. The findings from Stratton et al. (2007) and Boddy, Hackett and Stratton (2010) were in line with findings from the National Child Measurement Programme (NCMP), which also found a plateau during this period (National Health Service (NHS), 2019). Boddy, Hackett and Stratton (2010) also found that CRF declined over this period, independent of BMI and deprivation.

A second project that collected data on the CRF levels of children from a more affluent area of England (Chelmsford, Essex), is the Chelmsford Children's Fitness and Activity Survey (CCFAS). A study by Sandercock et al. (2010) tracked the secular changes of children between 1998 and 2008. The dataset was considerably smaller (n = 316 in 1998, n = 302 in 2008) than the SportsLinx project and only collected the data at the two time points, not annually. Sandercock et al. (2010) also found a significant decrease in CRF between 1998 and 2008, from 60 shuttles to 40 shuttles for boys and 46 shuttles to 29 shuttles for girls ($p < 0.001$). This represents an annual decline of -3.33% and -3.70% for boys and girls, respectively, in the CCFAS project compared to an annual decline of -1.34% and -2.29% for boys and girls, respectively, in the SportsLinx project. This difference in annual decline was due to the higher CRF levels of children who took part in the CCFAS (60 shuttles and 40 shuttles for boys and girls, respectively), compared to children who took part in SportsLinx in 1998 (47 shuttles and 34 shuttles for boys and girls, respectively). In the final round of data collection the difference between children from CCFAS (46 shuttles and 29 shuttles for boys and girls, respectively) and SportsLinx (42 shuttles and 29 shuttles for boys and girls, respectively) had decreased. When the data was reported as end speed, there were decreases from 11.6 km·h^{-1} to 10.8 km·h^{-1} for boys and from 11.1 km·h^{-1} to 10.2 km·h^{-1} for girls (Sandercock et al., 2010). This represents an annual decline of -0.7% and -0.9% for boys and girls, respectively. A second study by Sandercock, Ogunleye and Voss (2015) using data from the CCFAS reported on the secular changes between 2008 and 2014 (n = 307 in 2014). Sandercock, Ogunleye and Voss (2015) reported a lower annual rate of decline in CRF between 2008 and 2014 than between 1998 to 2008. The number of shuttles decreased from 40 to 33 for boys and 29 to 27 for girls, which represents an annual decline of -2.9% and -1.1% for boys and girls, respectively. The end speed decreased from 10.8 km·h^{-1} to 9.9 km·h^{-1} for boys and 10.2 km·h^{-1} to 9.8 km·h^{-1} for girls, which represents an annual decline of -1.4% and -0.7% for boys and girls, respectively. Sandercock, Ogunleye and Voss (2015) also reported that there was little change in BMI z-scores over this period with both boys and girls showing a decrease in BMI z-score, but not significantly (p = 0.06, p = 0.655, respectively).

A third project, the East of England Healthy Hearts Study (EOEHHS) assessed a variety of health markers linked to current and/or future disease risk in English children and adolescents. This project also used an observational, cross-sectional design, collecting data from over 8,000 participants aged 9-16 years between 2006 and 2011. This project was not used to monitor fitness levels but to investigate potential associations, such as between perceived parental PA (Voss & Sandercock, 2013), and difference in CRF between rural and urban youth (Sandercock, Ogunleye & Voss, 2011).

The studies produced as part of the SportsLinx and CCFAS projects (Boddy et al., 2012a; Sandercock et al., 2010; Sandercock, Ogunleye & Voss, 2015) show that CRF is continuing to decline in England, independent of BMI levels which appear to have plateaued. This suggests that continued reliance on BMI as a sole measure to monitor children's health status may not be enough. The data from these studies are now several years old, and use a repeated cross-sectional design, which do not show how the same participants' CRF changed over time. A recent study in England used a longitudinal design to track the CRF of 409 children aged 9-10 years from the North West of England over a 1-year period (Mann et al., 2018). Mann et al. (2018) found that children's CRF levels increased from Autumn Term to Spring Term by 3.8% (end speed) and this increase was maintained through to Summer Term but then decreased over the summer holiday period by 2.3% (end speed). This effect was amplified when deprivation was considered, with children from more deprived schools showing a higher decline in CRF over the summer holiday period (Mann et al., 2018).

2.3 National Fitness Testing in Schools

Previous large-scale studies have collected data on CRF of children in England, such as SportsLinx, CCFAS or EOEHHS (Boddy et al., 2012a; Sandercock et al., 2010; Sandercock, Ogunleye & Voss 2015; Voss & Sandercock, 2013). However, these projects are limited to certain regions in England and only used cross-sectional or serial cross-sectional designs.

Schools have been identified as an ideal location to implement population-based interventions to promote PA as no other institution has as much influence on children during their first two decades of life (Dobbins et al., 2013). Whilst schools alone cannot solve the problem of inactivity, they do have the potential to play a key role in ensuring that children and young people participate in the recommended amount of PA (Dobbins et al., 2013). Schools have also been highlighted as one of the most promising settings to implement CRF surveillance on a national scale for children and adolescents (Pate, 1989). Lang et al. (2018a) described how surveillance could be considered a population-based intervention, as regular measurement of CRF could develop a conversation around the topic. Currently, there are only a few countries that have implemented national testing of CRF in schools. One example of a country that has adopted measurement of CRF as a surveillance tool for children's health is Slovenia (Jurak et al., 2019). Slovenia provides a good example of how CRF surveillance can be utilised to improve health and is discussed below.

2.3.1 Slovenia Case Study

Slovenia is a pioneer when it comes to physical fitness monitoring on a population level, and this is done through the initiative SLOfit (Strel et al., 1997). SLOfit was introduced in 1987, and it is a national surveillance system for physical fitness and motor development of children and adolescents in Slovenia. SLOfit collects data from all children and adolescents aged 6-19 years and is compulsory for all primary and secondary schools in Slovenia (Strel, 2013). The SLOfit database is one of the largest cross-sectional and cohort databases in the world, with over 7 million sets of measurements from over 1 million children to date (Jurak et al., 2019). Every year, nearly all the Slovenian population aged 6 to 19 years (~220,000) are tested by eight motor tests and three anthropometric measurements (Jurak et al., 2019). These annual measurements allow researchers to monitor trends on a population level, as well as by regions, age-groups, or sex. The data allows teachers to identify which children may have special developmental needs and adjust their teaching methods to the needs and capabilities of the children in their class. SLOfit has also developed an evaluation and feedback system which allows parents and children to compare each child's development to their peers. On the national level, the data from SLOfit is used as a scientific platform for policies that are related to the improvement of PA of youth and school PE (Jurak et al., 2019).

The SLOfit initiative detected an accelerated increase in obesity since the mid-1990s, and it was predicted that childhood obesity would increase past 30% by 2020 (Starc, Strel & Kovac, 2010). Starc, Strel and Kovac (2010) proposed to the government that all children should receive an additional 2 hours of PE per week. The government then introduced the "Healthy Lifestyle" intervention in 2010 and the SLOfit system continued to monitor the children and found that the trends from 2010 to 2015 suggest that the prevalence of obesity in 2020 had now decreased to 22% (Jurak et al., 2019). The SLOFIT initiative demonstrates the important role of surveillance in monitoring a nation's health, informing government policies and evaluating interventions that are implemented – an example that England could follow.

2.4 Tracking of Cardiorespiratory Fitness

Given the documented declines in CRF levels of children and adolescents in recent decades, both in England (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015) and globally (Tomkinson et al., 2019b), monitoring of CRF is important. Additionally, using a longitudinal design makes it possible to track CRF levels across age-groups, from childhood onto adolescence and then into adulthood. Malina (2001) described how correlations in longitudinal studies rely on the strength of the measure, as well as the amount of time between measurements, with shorter periods of time resulting in larger tracking coefficients. In general, CRF has been found to track moderately well from adolescence to young adulthood with coefficients around 0.50 (Twisk, Kemper & van

Mechelen, 2000; Twisk, Kemper & van Mechelen, 2002). Studies have also shown that CRF tracks from childhood into adolescence, with correlation coefficients of 0.52 and 0.58 reported by True et al. (2021) and Pahkala et al. (2012), respectively. Tracking CRF using longitudinal data can provide information on critical windows of time for interventions throughout childhood and adolescence, as well as how CRF changes over developmental time. However, longitudinal CRF data are relatively difficult to obtain because of the time, cost and attrition rates (True et al., 2021). These reasons may explain the lack of longitudinal fitness studies involving the same participants conducted within England.

For longitudinal fitness studies with children and adolescents, maturation needs to be considered. Maturation is the process of children growing and obtaining adult stature (Lloyd & Oliver, 2019). Adolescence begins with the onset of puberty where hormonal and physical changes start to occur (Lloyd & Oliver, 2014). The onset of puberty can begin at any point from the ages of 8 to 14 years (NHS, 2018a). However, the average age for the start of puberty is younger for girls than boys, 11 and 12 years old respectively (NHS, 2018a). Fitness parameters, including CRF, are largely influenced by maturation (Malina, 1996). The differentiated growth rates and ages of the onset of puberty are likely to influence fitness differences between boys and girls (Malina, Bouchard & Bar-Or, 2004). However, a study by Tomkinson, Carver, Atkinson, Daniell and Lewis (2018) investigated the physical fitness of children and adolescents aged 9-17 years and they found that although boys performed substantially better than girls across all age-groups on muscular power, muscular strength, muscular endurance, speed-agility and CRF, the magnitude of the sex-specific differences did not accelerate until 12 years.

2.5 Fitness and Health Outcomes

2.5.1 Obesity

A person's weight status is commonly determined by calculating their BMI, using the person's height (m) and weight (kg) in the following formula; BMI = $kg{\cdot}m^{-2}$. The cut-points for different weight categories that are determined by a person's BMI in adulthood are shown in Table 2.3. Cole, Freeman and Preece (1995) produced age- and sex-specific reference curves to help identify a child's weight status to help account for maturity and growing.

Table 2. 3 BMI cut-points for weight status in adults (World Health Organisation (WHO), 2019)

Category	Cut-point ($kg{\cdot}m^{-2}$)
Underweight	< 18.5
Normal weight	18.5-24.9
Pre-obesity	25.0-29.9
Obesity class I	30.0-34.9
Obesity class II	35.0-39.9
Obesity class III	≥ 40.0

Obesity is caused by a sustained energy mismatch, where energy expenditure is exceeded by energy consumption (Power, 2012). If energy consumed through diet exceeds energy used then excess energy is stored as triglycerides in adipose tissue (Sun, Kusminski & Scherer, 2011). As the triglycerides increase in number and/or size they cause an increase in body mass (Sun, Kusminski & Scherer, 2011). An increase in the number of fat cells can lead to osteoarthritis (Issa & Griffin, 2012) and sleep apnoea (Bonsignore et al., 2012), whilst an increase in the size of fat cells can lead to several conditions, including type II diabetes, cancer and non-alcoholic fatty liver disease (Guh et al., 2009).

Diet and PA both help maintain the homeostasis of energy, and are key modifiable factors that contribute to people becoming obese. The relationship between PA and obesity is explored later in the literature review. Humans are more susceptible to obeseogenic environments due to their preference for energy dense food, weak satiety and strong hunger traits (Canoy & Buchan, 2007). The increased prevalence of overweight and obesity in developed countries has been associated with an increased consumption of snacks, fast foods and caloric beverages, as well as more high energy dense, palatable sweet foods (Drewnowski, 2009). Children's diets in England have been reported as too high in salt, sugar and saturated fats (Public Health England & Food Standards Agency, 2014). There are also certain eating habits such as snacking, consumption of sugar sweetened drinks and breakfast consumption that have been associated with higher prevalence of overweight and obesity in children (Isacco et al., 2012; Mota et al., 2009). In England, 14% of children have nothing to eat for breakfast, rising from 6% in primary school children to 20% in secondary school children (Hoyland et al., 2012). Sugar sweetened beverages, such as sugar soda and juices with added sugar content, are a common source of excess sugar consumption (Libuda & Kersting, 2009). The consumption of these drinks is increasing globally (Han & Powell, 2013). Ng et al. (2012) found that in the UK, 14% of children's energy intake is accounted for by drinks, with 79% of this energy coming from sugar-sweetened beverages.

Increased adiposity in childhood has been found to predict overweight in adulthood (Singh et al., 2008). However, a recent systematic review and meta-analysis found that anthropometric measures of obesity in childhood did not predict adult cardiovascular disease (CVD) event rates (Ajala et al., 2017). Ajala et al. (2017) suggested this may be due to the inaccuracies of the methods used to measure childhood obesity. The majority of the studies included in the review by Ajala et al. (2017) used BMI as a measure of obesity. BMI only provides a measure of body size and not body composition as it does not distinguish between fat mass and fat-free mass, and this may affect the ability of BMI to predict future risk (Simmonds et al., 2016).

2.5.1.1 Measurements of Body Composition and Body Size

Body composition is complex to measure as it is influenced by a range of factors and is made up of different components, including fat mass, minerals, protein and water (Hemysfield et al., 1996). The complexity of measuring body composition increases in childhood and adolescence due to changes resulting from growth and maturation but can provide valuable information on health if assessed accurately (Wells & Fewtrell, 2006). There are a number of methods to assess body composition with varying levels of accuracy and applicability. The gold standard method for measuring body composition is using cadaver analysis in chemical assay, so no *in vivo* technique can meet the highest criteria of accuracy (Wells & Fewtrell, 2006). Multicomponent models (e.g. combining body composition measures such as dual energy x-ray absorptiometry (DXA) and magnetic resonance imagery (MRI)) provide the gold standard for *in vivo* techniques in assessing body composition (Wells & Fewtrell, 2006). These types of techniques are expensive and not practical for use in large paediatric populations, so they will not be described further. Due to cost, strict testing procedures, and lack of availability and reference data, simple methods such as BMI, waist circumference and skinfold measurements are commonly used in paediatric populations. Skinfold thickness measurements can be used to predict body composition, whereas waist circumference provides a simple measure of central fatness and BMI is used an index of relative weight and as an index of nutritional status (Wells & Fewtrell, 2006). A summary of the advantages and disadvantages of these methods are shown in Table 2.4. Wells and Fewtrell (2006) described how a combination of these methods improves the accuracy in estimating body composition. However, the main measure used in England to assess the prevalence of childhood obesity by the NCMP and Health Survey for England (HSE) is BMI.

Table 2. 4 A summary of the advantages and disadvantages of body mass index, waist circumference and skinfold thickness measurements

Measurement	Advantages	Disadvantages
Body Mass Index	- Simple, cheap, quick, high availability. - Age percentiles and reference values available.	- Does not allow assessment of fat and lean masses separately. Assumes lean mass and fat mass weigh the same when lean mass weighs more. - Reference data do not take into consideration ethnic groups. - Measures nutritional status not body composition
Waist Circumference	- Simple, cheap, quick, high availability. - Assess central adiposity, which is more associated with cardiometabolic risk. - Detects small changes over time. - Reference values available.	- Assumes that it represents central adiposity. - Inaccurate estimate of internal visceral fat.
Skinfold Measurements	- Portable, cheap, quick, high availability. - Reference data available, with gender and ethnicity considered in some equations. - Measure of regional subcutaneous fat.	- Measurement precision and technique requires training. - No measure of lean mass.

2.5.1.2 Body Mass Index

BMI has been found to strongly correlate with body fat percentage, fat mass and total body fat (Chan et al., 1998; Pietrobelli et al., 1998, Lindsay et al., 2001). However, as previously mentioned BMI does not consider fat-free mass (Simmonds et al., 2016), and this can lead to issues when growth is a factor or there is change between lean and fat mass (Deurenberg, 2001; Malina & Katzmarzyk, 1999). This can result in a lack of validity during stages of growth in childhood and adolescence. Using age- and sex-specific percentiles to calculate z-scores such as those reported by Cole et al. (2000) can minimise these errors. However, using age- and sex-specific z-scores has also been found to be weakly associated with other measures of adiposity in obese and severely obese children (Freedman et al., 2017). A review by Simmonds et al. (2016) into the different measures of obesity in childhood found that BMI was reasonably good for diagnosing obesity in childhood, and that there was no convincing evidence suggesting that any other simple measure is better than BMI for diagnosing obesity in childhood.

2.5.1.3 Prevalence of Obesity

In England, the main source of data on the prevalence of overweight and obesity for adults is from the HSE. The proportion of adults who were overweight or obese steeply increased between 1993 and 2000, and there has been a slower increase since (NHS, 2018b). The prevalence of overweight or obese people has been between 61% and 63% since 2004, and was 64% in 2017 (NHS, 2018b). For children in England, there are two sources for the prevalence of overweight and obesity. The main source cited by the government is the NCMP, which includes nearly all children in Reception Year (aged 4-

5 years) and Year 6 (aged 10-11 years). The NCMP found that the prevalence of overweight or obesity in Reception Year has remained stable from 2006/07, where 22.9% were overweight or obese (with 9.9% obese), to 2018/19 where 22.6% were overweight with 9.7% obese (NHS, 2019). In Year 6 there has been an increase from 2009/10 where 33.4% were overweight or obese (with 18.7% obese) to 34.3% being overweight or obese (with 20.1% obese) in 2017/18 (NHS, 2019). The HSE also collects data on childhood obesity, and covers all children aged 2-15 years, however the number of children measured is a lot smaller than the NCMP. The HSE have found that the prevalence of children aged 2-15 years who were overweight or obese increased from 25% in 1995 to 34% in 2004, and was 30% in 2017 (NHS, 2018c). These childhood obesity rates mean that England is now ranked among the worst in Western Europe (Organisation for Economic Co-operation and Development (OECD), 2017).

2.5.1.4 Obesity and Cardiorespiratory Fitness

Physical fitness and PA are considered to be the main components that help protect against excessive weight gain in childhood and adolescence (Andersen et al., 2006; Blair et al., 1989). CRF has shown a stronger association with total adiposity than other physical fitness components (Ara et al., 2007). This finding is still evident for overweight or obese children, with children who have a higher CRF showing a lower overall adiposity (Nassis, Psarra & Sidossis, 2005). The majority of studies investigating the relationship between adiposity and CRF have been cross-sectional studies. A recent systematic review into the association between 20mMSR performance and adiposity reported that of the 83 cross-sectional studies, 66 studies found a favourable relationship (Lang et al., 2018c). Lang et al. (2018c) reported that 37 studies used BMI as a sole measure (32 studies found a favourable relationship), and 23 studies used BMI and another measure of body composition (14 studies found a favourable relationship).

There have been a number of longitudinal studies that have investigated the prevalence of overweight and obesity with CRF levels in childhood and adolescence. Several studies found that children and adolescents who were overweight or obese (measured by BMI) at follow-up had had lower CRF than their peers at baseline (Baranowski et al., 2013; He et al., 2011; Mota et al., 2009; McGavock et al., 2009; Savva et al., 2014; Aires et al., 2010a). There is also evidence from longitudinal studies that children and adolescents who improved their CRF from baseline decreased the risk of becoming overweight or obese in the future (Oretga et al., 2011; Rodrigues, Leitão & Lopes, 2013). The results of these cross-sectional and longitudinal studies demonstrate the association between obesity and CRF, and how improving CRF can decrease the risk of becoming obese.

2.5.2 Cardiometabolic disease and Cardiorespiratory Fitness

The World Health Organisation (WHO; 2017) referred to CVD as any disease of the cardiovascular system and is the leading cause of morbidity and early mortality globally. There are several modifiable factors that have been found to be associated with development of CVD, including physical inactivity, poor diet, hypertension, tobacco smoking and elevated blood glucose levels (Rizzo et al., 2007; Freedman et al., 2001). Epidemiological studies have found that CVD can begin in childhood and tracks through to adolescence and adulthood (Cote et al., 2015; Friedemann et al., 2012), therefore the modifiable risk factors that can be influenced in childhood need to be addressed. Due to the difficulties in following children who do not have potential risk factors into adulthood when CVD occurs, the follow-up in longitudinal studies has focused on CVD risk factors.

These risk factors include; obesity, high levels of triglycerides and cholesterol, insulin resistance, and high blood pressure (National Heart, Lung, and Blood Institute (NHLBI), 2012). These risk factors in childhood and adolescence have been found to be associated with more fatty streaks and fibrous plaques (Berenson et al., 1998), common artery intima media thickness (Raitakari et al., 2003), and artery calcification (Mahoney et al., 1996). A combination of these risk factors increases the likelihood of developing CVD.

Metabolic disorders are characterised by the inability to properly utilise and/or store energy, with the most widely recognised metabolic disorder being diabetes (Huynh, Schneider & Gareau, 2016). Steinberger et al. (2009) referred to cardiometabolic risk (CMR) as metabolic abnormalities which increase the risk of metabolic disorders or CVD, including glucose intolerance, type II diabetes and CVD. The development of CMR is defined as the clustering of 3 or more risk factors rather than any single risk factor being present (Steinberger et al., 2009). There have been numerous studies demonstrating that the origins of cardiometabolic disease (CMD) begin in childhood and adolescence (Bailey et al., 2013; Berenson, 2002). In the US, it is estimated that the prevalence of adolescents with CMR ranges between 4.5% and 9.2% (Tailor et al., 2010). In Europe, the prevalence of CMR was 0.2-1.4% in children aged 10-15 years, and 4.1% for adolescents aged 16-19 years (Makkes et al., 2013).

Poor levels of physical fitness in adults have been associated with higher risks of many health outcomes, including CMDs and all-cause mortality (Gupta et al., 2011; Ekblom et al., 2015; Bassuk & Manson, 2005; Kodama et al., 2009). Levels of CRF are regarded as an important indicator of health (Ortega et al., 2008a). Previous cross-sectional studies have shown strong correlations between CRF and CVD risk factors in children and adolescents (Hurtig-Wennlöff et al., 2007; Dencker et al., 2012; Aires et al., 2010b). The

Alimentación y Valoración del Estado Nutricional de los Adolescentes Españoles (AVENA) study showed that both overweight and normal weight Spanish adolescents who had high levels of CRF had more favourable metabolic profiles than those with low CRF (Mesa et al., 2006). These metabolic profiles were calculated from standardised values of high-density lipoproteins (HDL) and low-density lipoproteins (LDL) cholesterol, fasting glycaemia, and triglycerides. There is also evidence suggesting poor levels of CRF are associated with traits of paediatric type II diabetes mellitus. The European Youth Heart Study (EYHS) indicated that CRF explained a significant proportion of the homeostasis model assessment, insulin resistance and fasting insulin variance in children with high levels of body fat and waist circumference (Ruiz et al., 2007a).

A systematic review of 42 longitudinal studies, conducted by Ruiz et al. (2009), investigated the relationship between fitness levels in children and their future health. Ruiz et al. (2009) found that there was strong evidence that higher levels of CRF in childhood and adolescence was associated with a healthier cardiovascular profile later in life, including lower levels of blood lipids, blood pressure, and central and overall adiposity. However, another systematic review by Mintjens et al. (2018) found no convincing evidence of a significant association between CRF and future CVD risk factors. Mintjens et al. (2018) did find that of the studies that reported a significant association between CRF and future CVD risk factors, all showed that a higher CRF level was associated with lower future CVD risk factors, and that none of the included studies reported that higher CRF was associated with an increase in future CVD risk factors. Therefore, Mintjens et al. (2018) inferred that the overall longitudinal association between CRF and future CVD risk factors was probably weak to moderate. However, Mintjens et al. (2018) found that CRF was significantly associated with lower BMI, lower waist circumference, lower body fatness, and a lower prevalence for metabolic syndrome later in life.

2.5.2.1 Cardiorespiratory Fitness Cut-Points for Cardiometabolic Risk

Recently, Ruiz et al. (2016) conducted a systematic review and meta-analysis into CRF cut-points to avoid CVD risk in children and adolescents. Ruiz et al. (2016) found seven studies with children and adolescents from 14 countries that reported cut-points for CRF tests. Their meta-analysis found that fitness cut-points to avoid CVD fell between 41.8 and 47.0 $ml \cdot kg^{-1} \cdot min^{-1}$ in boys and 34.6 and 39.5 $ml \cdot kg^{-1} \cdot min^{-1}$ in girls aged 8-17 years. In the UK, Boddy et al. (2012b) reported a cut-point in the 20mMSR that determined whether children aged 9-10.9 years were at an increased risk of CMD. Boddy et al. (2012b) investigated whether the 20mMSR discriminated between healthy and overweight schoolchildren using a Receiver Operating Characteristic (ROC) analysis. Boddy et al. (2012b) also investigated whether CMR differed by the 20mMSR cut-point group by applying the ROC generated cut-point to a second, cross-sectional cohort. This was done in two stages. The first stage was that BMI, waist circumference, and body fat percentage were used in relation to 20mMSR performance on a large data set (16,619 children aged 9-10.9 years from the SportsLinx programme) to complete three ROC curve analyses. The mean of the three CRF cut-points were retained for analysis. The second stage involved applying the cut-points to clustered CMR data from the Welsh Schools study to assess whether risk differed by CRF group. The mean cut-point determined for the 20mMSR were 33 shuttles (46.6 $ml \cdot kg^{-1} \cdot min^{-1}$) for boys and 25 shuttles (41.9 $ml \cdot kg^{-1} \cdot min^{-1}$) for girls. Boddy et al. (2012b) found that participants classified as “fit” had significantly lower CMR scores in comparison to those classified as “unfit” ($p < 0.001$).

The early detection of CMR would allow the introduction of targeted interventions aimed at reducing CMR in children and the subsequent risks of early morbidity and mortality. However, the cut-points devised by Boddy et al. (2012b) have only been applied to one small cohort (n = 88) in Scotland (Houston et al., 2013). Houston et al. (2013) found that children who failed to reach the cut-points reported by Boddy et al. (2012b) had significantly higher clustered CMR scores. Using cut-points in the 20mMSR could provide a method to identify children at an increased risk of CMD non-invasively. The 20mMSR can be conducted on a large scale, therefore it would be an opportunity to screen for children at an increased risk of CMD at a population level.

2.5.3 Skeletal Health and Cardiorespiratory Fitness

Childhood and adolescence have been identified as important stages for determining long-term skeletal health (Bouchard, Blair & Haskell, 2012). Bone tissue is highly responsive to osteogenic stimuli, particularly during puberty (Weeks, Young & Beck, 2008). Therefore, if peak bone mass can be optimised during youth it may lead to the prevention of conditions such as osteoporosis in adulthood (Rizzoli et al., 2010; Eisman et al., 1993). In youth, participation in higher risk physical activities is at its highest (Bouchard, Blair & Haskell, 2012), and a high bone mass can also protect against bone fractures during this time (Clark et al., 2006). Skeletal health has been found to be favourably associated with another component of physical fitness, muscular fitness (Smith et al., 2014). There are fewer studies that have investigated the relationship between bone health and CRF. One study by Schneider et al. (2007) found that improvements in CRF over a 2-year period predicted an increase in bone formation and resorption in adolescence and young adulthood. Another longitudinal study found that there was a significant correlation between CRF and lumbar spinal bone mineral density, but that muscular fitness was the main physical fitness component related to adult bone mineral content (Barnekow-Bergkvist et al., 2006). Two further studies found muscular fitness was associated with future enhanced bone mineral density, but CRF was not (Vicente-Rodriguez et al., 2004; Kemper et al., 2000). Although this suggests that muscular fitness is the main predictor of bone density, due to PA being one of the modifiable determinants of peak bone mass (Babaroutsi et al., 2005), CRF should also be considered as having an indirect relationship due to the repeated loading on the musculoskeletal system during PA which can also improve CRF (Ortega et al., 2008a).

2.5.4 Psychological Health and Cardiorespiratory Fitness

The benefits of having a good level of fitness and being active during childhood should not be underestimated, with the benefits going beyond physical health. It is especially important for children and adolescents to form positive attitudes towards fitness and PA as these will continue into adulthood (ukactive, 2017). Psychological health is the presence of psychological well-being with the absence of psychological distress (Rodriguez-Ayllon et al., 2019). Psychological distress are emotions or unpleasant feelings that affect the level of functioning, for example depression, stress and mood disorders. Psychological well-being is defined as a combination of positive levels of functioning with optimal effectiveness in individual and social life, for example happiness, self-esteem and optimism (Antaramian et al., 2010). Having a good level of physical fitness has been shown to be associated with different psychological health indicators (Rodriguez-Ayllon et al., 2018). Specifically, CRF has been shown to be associated with reductions in psychological distress in adolescents (Shomaker et al., 2012; Williams et al., 2016), as well as better psychological well-being (i.e. optimism and self-esteem) in children (Rodriguez-Ayllon et al., 2018).

The mechanisms for which physical fitness promotes an increased resilience and positive psychological and physical health are complex and diverse. Silverman and Deuster (2014) found that a good level of physical fitness induces positive psychological and physiological benefits. Stress-related diseases are buffered by physical fitness due to the benefits on the hormonal stress responsive systems, such as the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system (Silverman & Deuster, 2014). This appears to increase positive mood and well-being and reduces emotional, physiological, and metabolic reactivity. Physical fitness also seems to minimise excessive inflammation (Silverman & Deuster, 2014). Psychological stress, abdominal adiposity, and physical inactivity have been associated with systemic, low-grade inflammation and can exert negative effects on physical health (Silverman & Deuster, 2014), including the maintaining or triggering of atherosclerosis (Libby, Ridker & Maseri, 2002; Ridker, 2001). These anti-inflammatory effects of good physical fitness can protect against various chronic diseases that are associated with systemic inflammation by improving behavioural and metabolic resilience (Silverman & Deuster, 2014).

2.5.5 Self-efficacy and Enjoyment in Physical Education

Self-efficacy and enjoyment are important mechanisms that underlie behaviours such as sport participation or PA (Bandura, 1997; Ryan & Deci, 2017). Self-efficacy is defined as an individual's belief about their capabilities to produce designated levels of performance that influence events that affect their lives (Bandura, 1994). Self-efficacy beliefs determine how an individual feels, thinks, behaves and motivate themselves (Bandura, 1994). In the context of PE, self-efficacy has been identified as an important correlate of PA and fitness in children and adolescents (Feltz, 1992; McAuley & Blissmer, 2000; Barnett, Morgan, van Beurden, Ball & Lubans, 2011). Promoting high self-efficacy in PE can have a positive impact on children's motivation and behaviour (Usher & Pajares, 2008), future health behaviours (Feltz & Magyar, 2006) and persistence in physical challenges (Gao, Lee & Harrison, 2008).

Enjoyment, in the context of PE, is a positive affective response as a result of participation that reflects feelings typically described as liking, pleasing and fun (Scanlen & Simons, 1992). Enjoyment experienced during PE lessons has been associated with higher intrinsic motivation, increased participation in PA and the adoption of active and healthy lifestyles (Wallhead & Buckworth, 2004; Dishman et al., 2005; Jaakkola et al., 2017; Bortoli et al., 2018; Vitali et al., 2019).

With self-efficacy and enjoyment being considered important correlates and determinants of PA and healthy behaviours (Lubans, Foster & Biddle, 2008), PE lessons need to ensure these mechanisms are not negatively impacted. There is a body of research that demonstrates consistent high levels of enjoyment in children and adolescents in PE (Carroll & Loumidis, 2001; Huhtiniemi et al., 2019). Previously, some studies have highlighted the potential negative impact fitness testing could have on children and adolescents' experiences in PE, including formation of negative attitudes towards PA (Dismore & Bailey, 2010), a decrease in motivation toward PE following low fitness test scores (Cale & Harris, 2009) and feelings of embarrassment when failing in front of peers (Alfrey & Gard, 2014; Cale & Harris, 2009). Research on students' perceptions to fitness testing in PE is limited and the findings are variable (Lodewyk & Muir, 2017; Jaakola et al., 2013; Hopple & Graham, 1995; Luke & Sinclair, 1991). However, a recent study by Huhtiniemi et al. (2021) found that although students' perceptions of enjoyment were lower in fitness testing PE lessons compared to PE in general, they did not significantly dislike fitness testing PE lessons. Furthermore, Cale, Harris and Chen (2014) found that the majority (73.5%) of secondary school Heads of PE believed that their students' responses to fitness testing were neutral or positive. However, research into the perceptions of primary school PE teachers or PE leads is lacking.

2.6 Physical Activity

The focus of this literature review has been around how and why CRF should be measured in schools and used as an indicator of health status of children. However, it is important to recognise that CRF is a physical trait that is primarily determined by PA behaviours (Lang et al., 2018a). Current population health surveillance initiatives have focused on behaviours, such as PA levels, which are associated with health outcomes (Tremblay et al., 2016; Hallal et al., 2012). It is therefore important to review PA, its association to CRF and health, how PA is measured and any limitations with those measures.

Total energy expenditure (TEE) is the sum of basal metabolic rate (i.e. the amount of energy expended used by the body at rest), the thermic effect of food (i.e. the amount of energy used to digest and eat food) and the energy used during PA (Westerterp, 2004). PA is the most adjustable component of energy expenditure (Cunningham, 1980), and accounts for approximately 30% of TEE, although this can vary depending on the individual's activity level (Abadi, Muhamad & Salamuddin, 2010). PA has four sub-dimensions, including frequency, intensity, time and type, also known as FITT (Gabriel et al., 2012). Frequency can be defined as the rate at which PA occurs over a period of time (Gabriel et al., 2012). Time (or duration) is the amount of time spent doing PA (Gabriel et al., 2012). Type of PA refers to activity that is being engaged in (i.e. walking, running or swimming; Gabriel et al., 2012). It is also important to understand that '*exercise'* is a subgroup of PA that is often confused with the term '*PA'*. Caspersen, Powell, and Christenson (1985) tried to define the differences between exercise and PA by considering the components of the activity. Caspersen, Powell, and Christenson (1985: 127) defined exercise as:

1) Body movement produced by skeletal muscles.
2) Resulting energy expenditure varying from low to high.
3) Very positively correlated with physical fitness.
4) Planned, structured, and repetitive bodily movement.
5) The objective is to maintain or improve physical fitness.

The intensity at which PA is engaged in is usually estimated as metabolic equivalents (METs). A MET is the ratio of a person's working metabolic rate relative to their resting metabolic rate. One MET refers to the resting metabolic rate, equivalent to 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ of oxygen consumption or 1 $kcal \cdot kg^{-1} \cdot hour^{-1}$ (Hills, Mokhtar & Byrne, 2014). It is important to note that MET values in adulthood are not applicable to children and adolescents (Aull et al., 2008; Bailey & McInnis, 2011), as youths have higher basal metabolic rates per unit of body mass which decreases as they get older (Butte et al., 2017). Butte et al. (2017) defined light-intensity PA as < 3 METs, moderate-intensity PA as 3-6 METs and vigorous-intensity PA as > 6 METs. However, the MET levels of moderate-intensity PA have varied in previous research, with Corbin and Le Masurier (2014) defining it between 4-7 METs. Moderate-intensity PA is the equivalent of 51-69% $\dot{V}O_{2max}$, and vigorous-intensity PA is the equivalent of ≥ 70% $\dot{V}O_{2max}$ (Hagströmer, Oja & Sjöström, 2007). Examples of moderate-intensity PA include bike riding and playground activities and examples of vigorous-intensity PA include fast running and sports, such as swimming and football.

2.6.1 Physical Activity Levels

In England, the current PA guidelines for children and young people are that they should: engage in MVPA for an average of ≥ 60 minutes per day across the week; engage in a variety of types and intensities of PA across the week; and aim to minimise the amount of time spent being sedentary (Department of Health & Social Care, 2019). Booth, Rowlands and Dollman (2015) found mixed results in their review of changes in trends of overall PA for children and adolescents over the last few decades. Booth, Rowlands and Dollman (2015) found that there was little evidence to suggest a decrease in overall PA which is supported by previous reviews (Dollman, Norton & Norton, 2005; Knuth & Hallal, 2009). This was due to inadequate baseline data, methodological inconsistencies between studies and a lack of research into specific PA contexts. There have only been a few studies that have investigated the trends of overall PA using objective measures. Three studies that did use objective measures found little or no significant change in overall PA (Raustorp & Ekroth, 2010; Sigmundová et al., 2011; Møller et al., 2009).

In 2018, the first *'Active Lives Children and Young People Survey'* report was published, which summarised the activity levels of children and young people (aged 5-16 years) in England from September 2017 to July 2018 (Sport England, 2018). Sport England (2018) reported that only 17.5% of children were meeting the Chief Medical Officers' (CMOs) guidelines of 60+ minutes of MVPA every day, with boys (20%) more likely to be active than girls (14%). Another survey that collects data on the PA levels of children and youth in England is the HSE. The HSE found that the proportion of children meeting the recommended PA guidelines, measured using a self-report questionnaire, decreased between 2008 and 2012 from 24% to 18% and increased to 22% by 2015 (NHS, 2016). The last objective measure of PA, using accelerometers, by the HSE was conducted in

2008 and found that 33% and 21% of boys and girls, respectively, met the PA guidelines. The self-report data in 2008 showed that 31% of boys and 22% of girls met the PA guidelines. Whilst the overall proportions of children meeting the PA guidelines appeared to be similar between the two measurements, there was a larger differentiation between younger and older children than is shown in the self-reported data. When comparing the two measurements in younger children they appeared to under-estimate their MVPA, whilst older children over-estimated their MVPA (NHS, 2009).

2.6.2 Relationship between Physical Activity and Cardiorespiratory Fitness

Bouchard and Shephard's (1994) conceptual model described the relationship between PA, health-related fitness, and health for adults. Lang et al. (2018a) published a modified version of the model for youth, shown in Figure 2.1. The model shows that CRF and PA are influenced by heredity, personal attributes (i.e. age and sex), and other lifestyle factors (i.e. diet), as well as physical and social environments. PA is described as taking place during active play, organised sport, active transportation, and school-based activities. The PA behaviours are positively related to several health-related fitness components, including CRF. Although the relationship between PA and CRF is weak to moderate in children and adolescents (Kristensen et al., 2010). Additionally, both health-related fitness and PA were independently associated with health (well-being, morbidity and mortality; Steele et al., 2008). Furthermore, there have been other models, such as Stodden's conceptual model (Stodden et al., 2008), which have also considered the importance of CRF in moderating the relationships between PA and motor competence.

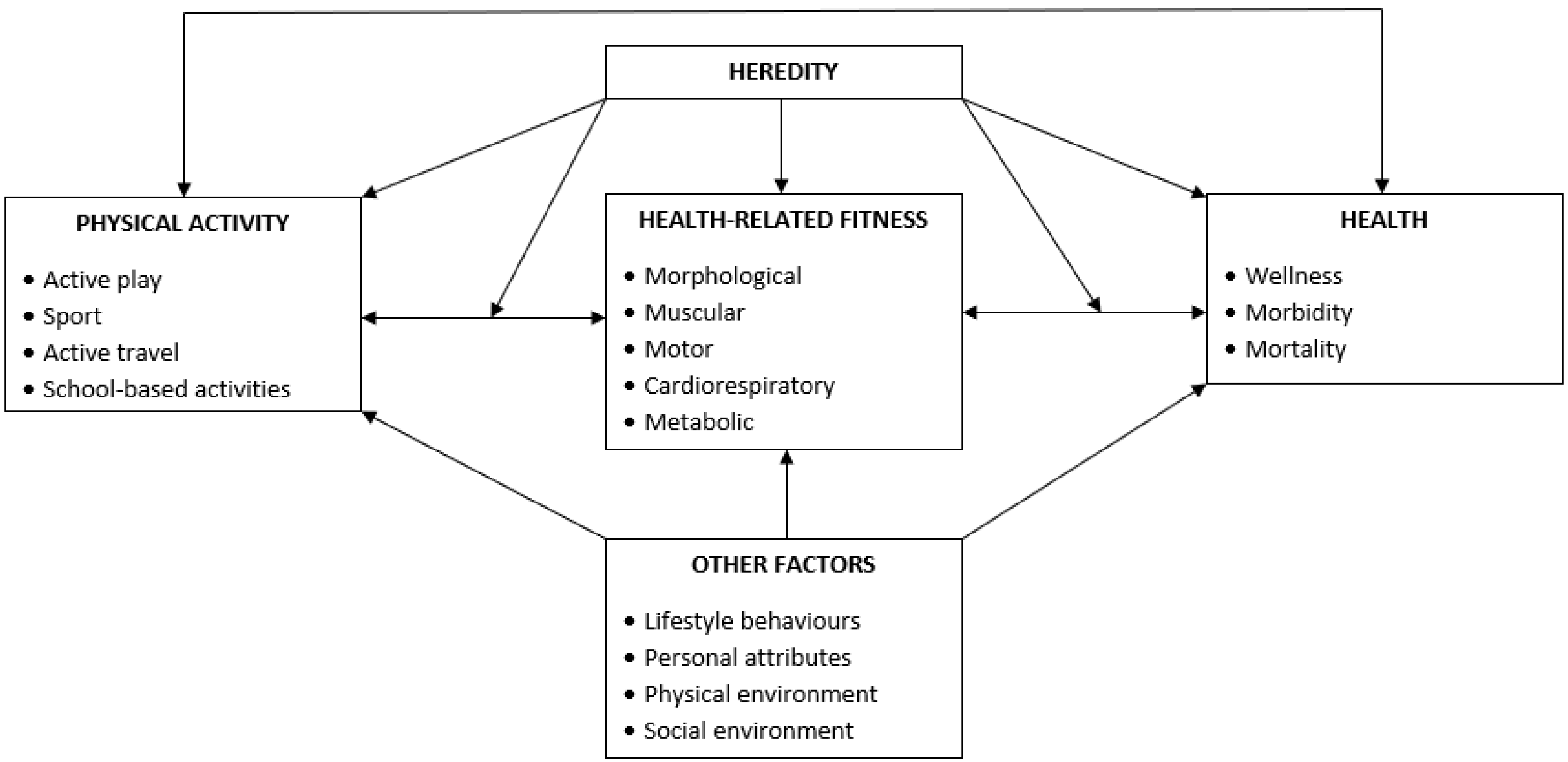

Figure 2. 1 Lang et al.'s modified version of Bouchard and Shephard's conceptual model for health-related fitness, PA, and health. Reproduced with permission

A positive relationship has been found between PA and CRF in children (Andersen et al., 2011; Larsen et al., 2015). However, the intensity of the PA moderates the strength of the association with CRF. Vigorous PA is more strongly associated with CRF (Dencker et al., 2008; Aires et al., 2010b), compared to lower intensities such as moderate PA (Ruiz et al., 2006a; Parikh & Stratton, 2011), and habitual PA has been found not to be associated with CRF (Armstrong, Tomkinson & Ekelund, 2011).

2.6.3 Measurement of Physical Activity in Epidemiology

There are a number of methods in which to measure PA. The ideal measurement of PA would capture all of its dimensions (frequency, intensity, duration and type of activity), but no single method currently exists. The doubly labelled water method is classified as the 'gold standard' for assessing energy expenditure (Sylvia et al., 2014). Doubly labelled water measures TEE in unrestrained humans in their normal surroundings over a period of 1-4 weeks (Speakman, 1997) and involves the participant consuming a loading dose of water labelled with the stable isotopes ^{2}H, which is eliminated as water, and ^{18}O, which is eliminated as water and carbon dioxide (Westerterp, 2009). The difference between the elimination rates can then be used to calculate TEE (Westerterp, 2009). Further detail on the doubly labelled water method is described by Westerterp (2009). However, this method is not appropriate for most research studies due to the cost, high subject burden, time-commitment and inability to collect qualitative data (Melanson & Freedson, 1996; Westerterp, 2009). Therefore, this method will not be discussed further in this thesis which is focussing on population level studies.

There are numerous measurement instruments to quantify PA, and they can be divided into subjective or objective methods. The cheapest and most convenient approach to collect PA data on a large-scale is through a subjective measure. Bauman et al. (2006) provided a summary of several self-report measures including self-report questionnaires, activity diaries or logs and direct observation. These methods have been used to estimate national and global PA levels across populations including youth (Hallal et al., 2012b). However, there are several disadvantages to using a subjective method which is self-reported, including recall bias (which is particularly evident in youth), measurement error and the reliability and validity of the instrument (Welk, Corbin & Dale, 2000; Shephard, 2003). Many national programmes that report the PA levels of youth use a self-reported measure such as questionnaires (Active Lives Survey, 2018). A further limitation of self-report measures is that youths, irrespective of age, have a poor ability to identify and understand different activity intensities (Crossley et al., 2019).

Objective assessments of PA, such as pedometers and accelerometers are being increasingly used in large-scale studies. Objective measurements avoid bias, and there is a greater confidence in the amount of PA measured, as well as an improved ability to associate PA to health outcomes (Reilly et al., 2008). Pedometers are small devices that measure the number of steps taken with a horizontal, spring-suspended lever arm which is deflected when the person's hip accelerates vertically with a force beyond a chosen threshold (Sylvia et al., 2014). Advantages of pedometers are that they are cheap, simple, and able to pick up short durations of PA that may be missed in self-report measures (Sylvia et al., 2014). However, pedometers do not measure the intensity, frequency or duration of PA, and have significantly less storage than accelerometers (Freedson & Miller, 2000).

Accelerometers have grown in popularity over recent decades as the tool to measure PA due to their accuracy, ability to capture large amounts of data, and ease of administration, particularly in larger studies (Westerterp, 2009). Accelerometers have also become the most widely used method to objectively assess habitual PA in youths (Cain et al., 2013; Ekelund et al., 2011). Therefore, accelerometers will be given more focus in this section of the literature review. Accelerometers detect movement in three orthogonal planes (vertical, mediolateral, and anteroposterior) and measure acceleration (counts) in real time (Rachele et al., 2012; Chen & Bassett, 2005). The devices can be worn on various parts of the body, including wrist, hip and thigh. Accelerometer data can be used to calculate the volume, rate, and time spent in different intensities of PA, and can be used for characterisations such as achieving public health guidelines (Tudor-Locke et al., 2010). Advantages of using accelerometers include minute-by-minute monitoring (Welk & Corbin, 1995), capturing PA intensity level (Healy et al., 2008), feasible to use with young children (Pate et al., 2006) and large memory capacities (Freedson & Miller, 2000). However, accelerometers are expensive and have limitations that relate to reliability (Chen & Bassett, 2005), insensitivity to certain activities (Trost, 2001) and participant compliance (Rowlands, 2007; Colley et al., 2011). Furthermore, there is not a standard protocol for managing the data, and some accelerometers cannot distinguish the body position (i.e. sitting, lying or standing) or the walking intensity (Hardy et al., 2013). Accelerometers are constantly improving and reducing the impact of these limitations and thus becoming a more common tool to assess PA in large groups of children and youth. However, the continued development of these devices can also have an impact on longitudinal studies. For example, one recent study in the US found that the proportion of adults meeting the US Department of Health and Human Services (DHHS) 2018 PA Guidelines for Americans and the ACSM's 2011 PA guidelines ranged from 3.4% to 95.6% (Zenko, Willis & White, 2019). Public health surveillance studies such as the

National Health and Nutrition Examination Survey (NHANES) in the US have shifted towards wrist-worn accelerometers instead of waist-worn accelerometers, and this is due to wrist-worn accelerometers being more convenient to wear which may lead to greater compliance during a prolonged wear time (Zhang et al., 2012). However, this increases the variability in the PA data and requires MVPA cut-points for both "lifestyle" and "ambulatory" activities (Zenko, Willis & White, 2019). These changes will create further difficulties when researchers attempt the longitudinal tracking of PA.

The validity of accelerometers can be derived from several components: cut-points, epoch length, accelerometer model, definition of a valid day, the required minimum wear time for a valid day, and the treatement of non-wear time (Cain et al., 2013). There are five Actigraph prediction equations that are regularly used to estimate cut-points for PA intensity levels of children and adolescents (Freedson, Pober & Janz, 2005; Puyan et al., 2002; Treuth et al., 2004; Mattocks et al., 2007; Evenson et al., 2008). The existence and use of multiple sets of intensity-related cut-points has significantly hindered research efforts to quantify, understand and intervene on the PA behaviours of children and adolescents, and has been referred to as the *"cut-point conundrum"* (Trost et al., 2011; Trost, 2007).

2.6.3.1 Intra-individual Variability

Intra-individual variability is another important consideration when considering measures used to monitor population health. PA is a behaviour and therefore has the potential to vary substantially day-to-day, meaning it has high intra-individual variability. Therefore, data is collected over 4 to 9 days (including a weekend day) to obtain a reliable PA measurement, with a reliability coefficient of 0.8 (Trost, 2001; Colley et al., 2011;

Fairclough, Butcher & Stratton, 2007). The high intra-individual variability of PA can result in an increase in participant burden and a decrease in compliance (Colley et al., 2011), an increase in financial cost (Chen & Bassett, 2005) and makes it more difficult to make comparisons due to weather and climate variations (Ridley et al., 2009). CRF, on the other hand, varies less on a day-to-day basis than PA as it is an innate trait which can be modified by PA, resulting in lower intra-individual variability. The reliability of CRF measured through the 20mMSR after one week was $r = 0.89$ for children and youth aged 8-19 years (Léger et al., 1988). More recently, Tomkinson and Olds (2008) reviewed 15 studies that investigated the reliability of the 20mMSR in children and youth and reported a sample weighted average coefficient of determination (r^2) of 0.73. The difficulty to obtain a reliable estimation of PA can result in uncertain associations with health markers, whereas the low intra-individual variability of CRF, through measures like the 20mMSR, often provides a clear association with health (Froberg & Andersen, 2005).

2.6.4 Physical Activity and Health

The impact of physical inactivity and sedentary lifestyles are estimated to cost the economy in the UK as much as £1.2 billion a year (British Heart Foundation, 2017). Physical inactivity has been identified as the fourth leading risk factor for global mortality (WHO, 2010). PA has been found to provide immediate and long-term health benefits (Strong et al., 2005; Telama et al., 2013; Shiri et al., 2013), and is a key contributor for a healthy lifestyle (Nelson et al., 2007; Saunders et al., 2016). Higher PA levels have been found to reduce the risk of coronary heart disease (Li & Siegrist, 2012), hypertension (Peters et al., 2006), type II diabetes (LaMonte et al., 2005), stroke (Goldstein, 2010), certain types of cancer (Wolin et al., 2009) and depression (Martinsen, 2008).

A physically active lifestyle is positively associated with many physiological and psychological health benefits in children (Janssen & LeBlanc, 2010). There is evidence of beneficial effects of PA on musculoskeletal health, several components of CVD, adiposity, and blood pressure (Strong et al., 2005; Katzmarzyk et al., 2015; Biddle, Gorley & Stensel, 2004; Webber & Loescher, 2013). Boreham and Riddoch (2001) described three main benefits of promoting PA in childhood: A direct improvement of health status and quality of life during childhood; a direct improvement in adulthood by delaying the onset of non-communicable diseases (NCDs); an indirect health gain due to the likelihood of forming positive activity behaviours during childhood that are more likely to be maintained into adulthood. The intensity and duration of PA also needs to be considered when trying to improve the health or fitness of an individual, with moderate or vigorous PA having health enhancing benefits (Hagströmer, Oja & Sjöström, 2007).

When comparing the relationships between CRF and PA with CVD and metabolic profiles in children and adolescents, the association appears to be stronger for CRF (Hurtig-Wennlöf et al., 2007; Rizzo et al., 2007). Furthermore, Andersen et al. (2011) found that clustering of CVD risk factors developed between the ages of 6 and 9 years in children, and that at 9 years clustered CVD risk was highly associated with low CRF. Andersen et al. (2011) also used an objective measurement of PA but found no association. Furthermore, studies that have compared the relationship of CRF and PA with health have found that CRF is associated with better health in children and adolescents, independent of PA (Ekelund et al., 2007; Steele et al., 2008). These findings suggest that measuring CRF provides a better representation of the health status of children, compared to measuring PA.

2.6.5 Comparison of Physical Activity and Cardiorespiratory Fitness Surveillance Studies

The Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) project is a study that investigates the nutritional status and lifestyle of adolescents with the same methodology throughout several countries (Moreno et al., 2008). This project followed on from a “precursor” study, AVENA, which was a multi-centre cross-sectional study on Spanish adolescents (Moreno et al., 2008). One study conducted as part of the HELENA project described a ‘European gradient’ after finding that adolescents from Northern European countries were more physically active than adolescents from Southern European countries (Ruiz et al., 2011a). These results are like the findings of Lang et al. (2018b), who found in a 50-country comparison of 20mMSR performance that children and adolescents from Northern Europe countries had better CRF, compared to children from Southern European countries.

The Active Healthy Kids Global Alliance’s report cards on the PA of children and adolescents are used to help understand the PA levels of youth between different countries (Tremblay et al., 2016). Researchers from different countries collect recent data on their national PA levels using harmonised methods. To date, report cards have been published for 38 countries and have been used to identify low PA levels in some North American, South American, and Asian countries, as well as high PA levels in some African, Oceanic, and Northern European countries (Tremblay et al., 2016). Nationally representative samples of PA levels assessed using objective measures are rare and are only available from a few high-income countries. The International Children’s Accelerometry Database (ICAD) is the largest dataset of collective objective measures (Sherar et al., 2011). A study by Cooper et al. (2015) used data from ICAD to compare the PA levels of children and adolescents in 10 countries and found that children from Northern European countries had higher PA levels. Again, these findings are like that of Lang et al. (2018b), who found children and adolescents from Northern Europe and African countries had better CRF, whilst children and adolescents from South American countries had the lowest levels of CRF. These findings demonstrate that CRF provides a reasonably accurate representation of objectively measured PA levels in nationally representative samples. Therefore, if measuring PA through objective methods is not possible due to human resource or financial restrictions, then the measurement of CRF through a validated, reliable, and scalable test, such as the 20mMSR, is a feasible option. Due to CRF predicting health outcomes independent of PA (Ekelund et al., 2007; Steele et al., 2008), measurement of CRF should not be disregarded in high income countries where surveillance systems of objective measurements of PA are already in place, as this would provide more information on children's health status than measuring PA alone.

2.7 Academic Performance, Executive Function and Cardiorespiratory Fitness

A large proportion of children and adolescents can be accessed, monitored and influenced for the majority of the year in schools, which makes them an ideal setting for interventions to improve CRF (Tomporowski, Lambourne & Okumara, 2011). However, there is pressure on schools to perform better academically in subjects such as reading and mathematics, which can lead to less emphasis on subjects such as PE (Coe et al., 2006; Tsai et al., 2009; Arnold et al., 2016), despite evidence demonstrating the link between PA and CRF with both executive function and academic performance (Santana et al., 2017; Donnelly et al., 2016).

Executive function can be defined as a group of mental processes that are required when you have to pay attention or concentrate on a task (Diamond, 2013). These are required when relying upon instinct would be insufficient, ill-advised or impossible (Burgess & Simons, 2005; Epsy, 2004; Miller & Cohen, 2001). Executive function has been found to be associated with an increase in on-task behaviour (the amount of time spent working on a learning task), as well as the ability to inhibit off-task behaviour whilst in a learning environment (Hofmann, Schmeichel & Baddeley, 2012). Previous studies have also shown that executive function is associated with academic performance (Haile et al., 2016), classroom behaviours (Singh et al., 2012), and mental health (Diamond & Ling, 2016). The literature described executive function as having three sub-domains; *"inhibition"*, *"working memory"* and *"cognitive flexibility"* (Lehto et al., 2003; Miyake et al., 2000). Inhibition (also called *"selective attention"*) involves the ability to control one's attention, thoughts, emotions, and/or behaviour, and to override an internal predisposition or distraction to do what is more needed or appropriate (Diamond, 2013). If people did not use inhibition, then they would be at the mercy of impulses, previous behaviours and the stimuli of the environment. Inhibition can be assessed through several psychological tasks, including Stroop task (MacLeod, 1991), Flanker task (Eriksen & Eriksen, 1974; Mullane et al., 2009), antisaccade tasks (Luna, 2009; Munoz & Everling, 2004), go/no-go tasks (Cragg & Nation, 2008) and stop-signal tasks (Verbruggen & Logan, 2008). Working memory (also called *"updating"*) involves holding information in one's mind and mentally working with it (Baddeley & Hitch, 1994; Smith & Jonides, 1999). There are two types of working memory, verbal and non-verbal (visual-spatial). Working memory is important for anything that happens over time, as it requires keeping something in mind that happened earlier and relating it to what happens next (Diamond, 2013). Psychological tasks that assess working memory include backward digit span tasks (Diamond, 2013), Corsi Block test (Lezak et al., 2012), Self-Ordered Pointing task (Petrides et al., 1993; Petrides & Milner, 1982) and reading or counting span tasks (Barrouillet et al., 2009; Case, 1995; Conway et al., 2005; Daneman & Carpenter, 1980). Cognitive flexibility (also called *"shifting"*) builds on the previous two sub-domains of executive function and involves a person being able to change how they think about something, and if they can change their perspectives both spatially and interpersonally (Diamond, 2013). There are a number of psychological tasks that assess cognitive flexibility, including design fluency, verbal fluency and category fluency (Diamond, 2013). There are a wide range of task-switching and set-shifting tasks that assess cognitive flexibility, the oldest and most recognised being the Wisconsin Card Sorting Task (Milner, 1964; Stuss et al., 2000). Each of these sub-domains have been found to be associated with academic performance in children (St Clair-Thompson & Gathercole, 2006) and adolescents (Gathercole et al., 2004). These sub-domains of executive function also build higher order executive functions such as planning, reasoning and problem-solving (Lunt et al., 2012; Collins & Koechlin, 2012), which are important for many aspects of life, including physical and mental health, school and job success, and social and psychological development (Diamond, 2013).

North, McCullagh and Tran (1990) suggested that CRF is a physiological mediator that explains various mental health benefits of PA. An improvement in the heart's ability to deliver oxygen to the muscles, as a result of more regular MVPA, CRF increases (ACSM, 2010). The increases in CRF are believed to be associated with inducing angiogenesis in the motor cortex and increasing blood flow, which improves brain vascularisation (Hillman, Erickson & Kramer, 2008). In animal studies, long-term physical exercise has been shown to cause neurostructural changes and increase the upregulation of multiple neurotrophic factors which influence learning and memory (Voss et al., 2011; Dishman et al., 2006; Ferris, Williams & Shen, 2007; Flöel et al., 2010). Additionally, in normal-ageing adults reduced white matter integrity has been found to be associated with poorer inhibition (Marks et al., 2007), whilst CRF has been found to be positively associated with white matter integrity (Colcombe et al., 2006). Furthermore, children with higher CRF levels have been found to have larger volumes of basal ganglia and hippocampus compared to children with low levels of CRF (Chaddock et al., 2010).

Minatto et al. (2016) found that PA and exercise interventions, aimed at increasing CRF, had a moderate significant effect on CRF regardless of intensity, although interventions that did not control the intensity of PA or exercise did not have a significant effect. Minatto et al. (2016) also found that the CRF improved when different types of exercise were used in the interventions, including aerobic, resistance and a combination of the two. There have been numerous types of interventions and intensities of exercise that have been shown to have an impact on executive function across populations, including aerobic exercise (Guiney & Machado, 2012), moderate intensity exercise (McArdle, Katch & Katch, 2006), resistance training (Best et al., 2015; Liu-Ambrose et al., 2012), complex forms of motor training that include physical and cognitive demands (Moreau, Morrison & Conway, 2015; Tomporowski, McCullick & Pesce, 2015) and high intensity exercise (Moreau, Kirk & Waldie, 2017). Therefore, it could be hypothesised that improving CRF, through a PA intervention, may lead to improvements in children's executive function and how they perform academically. This would also be in addition to the numerous physical and mental health benefits that are associated with improving CRF levels (Ortega et al., 2008a).

When reviewing the literature for the link between CRF and PA with executive function and academic performance, there are several systematic reviews and meta-analyses that have been published previously. A meta-regression was conducted in 2006 investigating the relationship between CRF and cognitive performance (Etnier et al., 2006), and found no significant effect of CRF on cognitive performance. However, most of the studies included in their review were based on adult populations. In the last decade there has been a growing interest into the possible relationship between CRF with executive function and academic performance in children and youth. Narrative reviews by Haapala (2013) and Keeley and Fox (2009) described research reporting a positive association between executive function and academic performance with CRF. There have also been three systematic reviews published, which suggest that there are positive associations between CRF and PA with executive function and academic performance (Marques et al., 2018; Donnelly et al., 2016; Santana et al., 2017). However, most of the studies included in these reviews were cross-sectional studies, and the findings for the intervention studies were inconsistent. This may be due to several reasons. Firstly, cross-sectional studies may not be accounting for significant covariates such as socio-economic status (SES), age, nutritional status, home environment, family roles and psychosocial variables. Secondly, the measure of academic performance varies across studies, with several different standardised tests being reported. Finally, the wide variation in PA interventions may explain the mixed results found in controlled experiments in the review.

There have been four meta-analyses focusing on the impact of PA interventions on executive function and academic performance (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018; Álvarez-Bueno et al., 2020). These meta-analyses found small significant effects for the PA intervention groups for executive function and academic performance (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018), whilst Álvarez-Bueno et al. (2020) found that CRF was positively associated with academic performance. However, these analyses have primarily, though not exclusively, examined cross-sectional associations between PA/CRF and executive function/academic performance as opposed to intervention studies. Further, it is typically assumed that PA interventions have improved CRF despite there being only moderate evidence for this effect in school-based interventions (Minatto et al., 2016; Pozuelo-Carrascosa et al., 2018). Thus, it is similarly assumed in line with cross-sectional data linking CRF with executive function or academic performance, that it is a mechanism that might be involved in their improvement. However, previous meta-analyses have not examined the moderating effect of PA induced increases in CRF (compared to a control group) upon changes in executive function and academic performance.

2.8 Socio-economic Status

SES is often measured by levels of deprivation. Deprivation is defined as the lack of access to opportunities and resources considered to be basic necessities in society (Department for Communities & Local Government, 2015). The English Indices of Multiple Deprivation (IMD) is made up of seven domains of deprivatio, including income, employment, health, education, crime, barriers to housing and services, and living environment (Department for Communities & Local Government, 2015). If there is a concentration of people suffering from more than one of these domains, then the area has multiple deprivations (Department for Communities & Local Government, 2015). Another common measure of SES in children is whether they are eligible for free/reduced priced meals, also known as the Pupil Premium (PP) in England.

There is clear evidence that health is not distributed equally across society with many aspects of health, such as obesity, highlighted by social and economic inequalities (The Marmot Review Team, 2010). The NCMP demonstrates this social gradient in children, and the difference in the prevalence of obesity between children from most deprived backgrounds with children from least deprived backgrounds is increasing (NHS, 2019). In Reception, the difference increased from 4.5% in 2006/2007 to 6.5% in 2018/2019, and in Year 6 children it increased from 8.5% in 2006/2007 to 13.9% in 2018/2019 (NHS, 2019).

The association between PA with SES is complicated, and this could potentially be due to the varied measures that have been used in the literature (Roberts et al., 2013). In adults, the Active People Survey found that people with a high SES were more likely to participate in regular PA and sport compared to those from a low SES, demonstrating a social gradient (Hillsdon, 2011). Studies that have focused on parental income and extracurricular use of sport facilities indicate that the participation of children from low income families is significantly less than those from high income families (Voss et al., 2008; Ziviani et al., 2008). A study by Brockman et al. (2009) investigated the influences of SES on PA in primary school children in Bristol in England. Brockman et al. (2009) reported that time was a barrier to children from all SES groups, whilst cost was a significant barrier to children from low SES schools. Furthermore, Brockman et al. (2009) found that children from middle/high SES schools engaged in more sports clubs and organised activities, whilst children from low SES schools participated in more unstructured activities or “free play” with friends. Irrespective of the PA mode engaged in, any impact of SES upon engagement in PA appears more likely to influence children in early years.

In Europe, Jiménez-Pavón et al. (2010) reported a positive association between SES and physical fitness (including CRF) of European adolescents, independent of body fat and PA. However, results of studies from individual countries have varied, with some showing an inverse association between SES and CRF (Freitas et al., 2007). These discrepancies may be due to specific and cultural differences of each country, as well as the methodologies used. In England, the association of SES and CRF has also shown mixed results, with some showing a positive relationship (Charlton et al., 2014; Noonan et al., 2016) and others showing no significant effect (Brophy et al., 2012). A recent study by Nevill et al. (2018) found that there was a strong association between obesity and deprivation in English adolescents. However, when CRF and PA were added to the model the odds of obesity were reduced, although it was only when CRF was included that the association between obesity and deprivation disappeared (Nevill et al., 2018).

2.9 Summary and Conclusion

The literature review in this chapter has summarised the key and current evidence surrounding the measurement of CRF and its relationship with the following; current and future physical health, psychological health, PA, executive function and academic performance. Furthermore, the review has also highlighted the previous studies in England and across the world that have examined the CRF levels and trends of children and youth.

The promotion of PA has been identified as a public health priority in England and globally, with a number of strategies released in recent years. To evaluate the effect of any intervention or strategy, monitoring systems need to be implemented. The surveillance of PA among youth has been labelled as the primary measure to track and compare the health of children and adolescents across regions and countries (Hallal et al., 2012b). The identification of PA as a primary surveillance indicator is part of the reason that PA guidelines have been developed and distributed. However, the methods used to measure PA objectively have changed considerably over the years, and the use of accelerometers as a surveillance measure in paediatric populations is relatively new. Therefore, the consistent use of objective measures of PA are only available in a few high-income countries. Furthermore, the PA guidelines were created with the consideration that PA is a behaviour, that when increased, causes outcomes such as improved CRF.

CRF has not been highlighted or recognised in the same manner as a surveillance measure as PA, even though CRF in childhood is an important marker of current and future health, independent of PA levels (Ortega et al., 2008b; Ruiz et al., 2009; Ekelund et al., 2007). Furthermore, improving children's CRF is arguably one of the intended outcomes of any PA intervention. Monitoring CRF levels could be used to consider whether any behaviour changes in PA (e.g. more people meeting the PA guidelines) are producing concomitant improvements in children's fitness. There is evidence in the literature that the CRF of youth is still declining globally, a trend that is also seen in England. There are very few studies that report the levels of CRF in England and these are studies carried out by researchers in specific regions of the country. In England, the only measure to monitor children's health status on a national scale is BMI, which has a very weak relationship with PA at best. However, it allows the government, researchers, and public agencies the opportunity to track and compare the prevalence of obesity on a population-level on a national scale, as well as between regions and groups (i.e. SES). The recent strategies released by governing bodies in England are aiming to increase the PA levels of the youth population. However, the bias associated with subjective measures of PA may change over time, making these measures problematic. Lang et al. (2018a) identified the measurement of CRF as a feasible way to study the link between PA and health in children and adolescents at a population level. Indeed, the use of CRF as a surveillance tool was called for by the former CMO for England almost a decade ago, yet no initiative has been put in place.

2.9.1 Objectives

This thesis aims to consider whether there is a case to implement CRF testing in primary schools in England. This thesis has a number of objectives that will consider the strength of the case for the measurement of CRF as a surveillance tool in England, including the following:

1) To conduct a systematic review, meta-analysis, and meta-regression of PA intervention studies to examine the impact of changes in CRF, as a result of the PA intervention, on executive function and academic performance in children and adolescents.
2) To conduct a cohort comparison of studies that have collected data on children's CRF.
    i) Conduct a cohort comparison with other English studies that have measured CRF of children.
    ii) To perform a cross-country comparison of CRF levels between children from England and a convenience sample from the US.
3) To identify and compare the proportion of children classified at an increased risk of CMD by BMI and CRF cut-points.

4) To explore the longitudinal changes in CRF of primary school children over a 3-year period and examine the effects of SES on these trends.
5) To examine teachers' perceptions of fitness testing delivery in primary schools through semi-structured interviews.

CHAPTER 3.0 GENERAL METHODS

The methods described in this chapter are the generic field-based methods that were used in this thesis. Specific methods described in detail and statistical analyses are outlined in the relevant studies.

3.1 Ethical Approval

Ethical approval for Study 2 (P60795 & P68526: Appendices I & II), Study 3 (P60795: Appendix I), Study 4 (P60795: Appendix I), and Study 5 (P82273: Appendix III) were granted in agreement with the guidelines and policies of Coventry University research ethics committee. For Studies 2, 3 and 4, information sheets were developed for headteachers and parents/guardians and prior to study engagement informed consent from headteachers and parents/guardians was obtained, as well as child assent. For Study 5, information sheets were developed for teachers who were the participants and informed consent was obtained.

3.2 Testing Personnel

Premier Education is a Physical Education (PE) provider and children’s coaching company which operates in over 3000 schools throughout the UK and delivers over 25,000 physical activity (PA) sessions each month. These sessions are in the form of curricular PE lessons, or extra-curricular activities such as breakfast clubs, lunchtime clubs, or after-school clubs. This organisation was identified by ukactive as being well placed to deliver the type of fitness testing required on the large scale necessary for this project. All the coaches employed by Premier Education are qualified with a minimum level 2 coaching qualification in at least one sport, with first aid training and enhanced Disclosure and Barring Service (DBS) checks. All coaches who took part in the data collection received augmented training in the collection and management of the data by the thesis author.

3.3 Participants and Settings

Twenty of the 96 primary schools in the London boroughs of Camden and Islington were invited to take part in the project, and seventeen schools agreed to participate. All testing was completed by staff from Premier Education. Data was collected at five time-points across three academic years between September 2016 and December 2018 (Autumn Term 2016, Summer Term 2017, Autumn Term 2017, Summer Term 2018 and Autumn Term 2018).

All children in academic Years 4 to 6 (aged 8-11 years old) were invited to take part in the study. Due to the different study designs, the number of participants that were used in each study will be described in the relevant study's method section. The data collection took place on site at each school during a scheduled PE lesson. Participants completed the tests in their PE kit and whilst wearing appropriate sports footwear.

3.4 Procedures

3.4.1 My Personal Best Challenge

The My Personal Best Challenge (MPBC) involved children completing the 20m Multistage Shuttle Run (20mMSR) and having their height and weight measured. The emphasis of the MPBC was on the 20mMSR, whilst height and weight were additional measures. The MPBC is one of a number of programmes being administered by Premier Education in primary schools across the country. Previously, Premier Education has partnered with ukactive and Aberystwyth University in a pilot study of the MPBC. This was implemented in the North West of England over a 12-month period and the findings of the study have since been published (Mann et al., 2019). The MPBC focuses on individual performance, and emphasis during the instruction is put on children achieving their best score in the 20mMSR, then aiming to better this in subsequent measurements. Details of the lesson plan for the MPBC can be found in the Appendix IV.

3.4.2 Cardiorespiratory Fitness

The 20mMSR involves running back and forth continuously between two parallel lines that are 20m apart in time to audio signals. It comprises of stages or levels, which last approximately one minute, with each stage comprised of a number of 20m shuttles or laps. At each stage, the required running speed increases, until the participant can no longer run the 20m distance in time with the audio signals. The test score achieved by the participant was the number of 20m shuttles completed before the participant either withdrew voluntarily from the test or failed to reach the end line on two consecutive tones. Children were encouraged to run to exhaustion, and the number of shuttles completed was recorded for each participant. Children who were not participating were also asked to encourage and support their peers so that they kept pushing themselves.

The protocol adopted for the MPBC was the Léger et al. protocol (Léger et al., 1984; Léger et al., 1988) as this was found to have a higher criterion validity than the other protocols (Mayorga-Vega et al., 2015). Participants completed the 20m shuttles with an initial speed of $8.5km \cdot h^{-1}$, increasing by $0.5km \cdot h^{-1}$ each minute. The different metrics of the 20mMSR should be reported, including the number of shuttles and the end running speed (Tomkinson et al., 2019a). The two approaches that are commonly used to interpret the 20mMSR results are: health-related criterion-referenced standards or normative-referenced standards. For comparison to health-related criterion-referenced standards peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) will be calculated using the Léger et al. (1984) equation, shown in Table 2.1. Normative-referenced standards will be used to compare differences in cardiorespiratory fitness (CRF) between participants of different ages and sex, also known as z-scores. Z-scores were calculated by using the methodology highlighted by Voss and Sandercock (2009) and the age- and sex-specific global mean and standard deviation values for children presented by Tomkinson et al. (2017). Compared to the mean global score for children of the same age and sex, a positive z-score indicates a higher than average test score, a negative z-score indicates a lower than average test score, and a z-score of zero indicates the test score is equal to the mean (Voss & Sandercock, 2009).

3.4.3 Age

The dates on which the children completed the fitness test and the anthropometric measures were recorded and were used with their date of birth to calculate their decimal age. Six schools did not provide date of birth for their pupils. If this was the case, children were assigned a date of birth halfway through the academic year (*n* = 670).

3.4.4 Anthropometry

Anthropometry measures were carried out in a private, one-to-one basis to ensure privacy and confidentiality of data. All participants were asked to wear lightweight PE clothing and asked to remove their shoes, pull-overs (if wearing one) and anything in their pockets.

3.4.4.1 Stature

Participants were asked to remove footwear and stand upright against a stadiometer (Seca 213 portable stadiometer). Children were asked to look straight ahead and keep their head level. The vertical distance between the floor and the top of the skull was measured to the nearest 0.1 cm. Participants were asked to breathe in when measured.

3.4.4.2 Body Mass

Participants were tested in light, athletic clothing and asked to remove their shoes, pull-overs (if wearing one) and anything in their pockets. They were measured using scales to the nearest 0.1 kg (Seca 876, Hamberg, Germany).

3.4.4.3 Body mass index

Obesity and overweight are often measured using body mass index (BMI), where body mass in kilograms is divided by height in metres squared. Due to stages of growth and development for children, the adult cut-points are not suitable for assessing whether a child is underweight, healthy, overweight, or obese (Cole et al., 2000). Therefore, age- and sex-specific cut-points have been devised. In the UK, the most commonly used cut-points are based on the UK1990 Child Growth Foundation reference charts (Cole, Freeman & Preece, 1995). Percentile curves were calculated using the LMS method (Cole, Freeman & Preece, 1995). The LMS method uses 3 curves called lambda (λ or L), mu (μ or M), and sigma (σ or S), where the L curve allows for the skewness in BMI caused by age, and M and S represent the median and coefficient of variation of BMI at each age. The 85^{th} percentile is used to define children as being overweight and the 95^{th} percentile for children who are obese.

3.4.5 Deprivation

Deprivation was measured on a school level using two methods.

1) Participants were assigned a deprivation rank based on the Lower-layer Super Output Area in which their school was situated using the school's postcode. Deprivation was calculated from each school's postcode using the English IMD 2015 (Department for Communities and Local Government 2015).
2) If a participant's parents' household income is below a certain amount, then the child qualifies for the Pupil Premium (PP) and receives benefits from the school funded by the government, such as free school lunch. The percentage of children that were entitled to the PP that were enrolled at the school was collected. This proxy measure of school-level socio-economic status (SES) has been used in previous research studies with children (Mackintosh et al., 2011).

3.5 Role of Thesis Author

The thesis author conducted the systematic review, performed the meta-analysis and summarised the findings in Study 1. For the findings presented in Study 2, Study 3 and Study 4 the thesis author conducted training for Premier Education staff who were responsible for data collection at the primary schools in England. The thesis author attended the first MPBC session that each coach administered to ensure the testing procedures were being conducted correctly. The thesis author also trained the staff member from Premier Education who was responsible for operations and administering the MPBC to children in the US which were reported in Study 2. The thesis author was also responsible for liaising with headteachers and PE leads at the primary schools in England that were not already employing Premier Education staff as well as conducting the testing sessions at these schools if a Premier Education coach would be unable to attend. For Study 5, the thesis author conducted the interviews with the primary school teachers.

CHAPTER 4.0 STUDY 1: DO CHANGES IN CARDIORESPIRATORY FITNESS RESULTING FROM PHYSICAL ACTIVTIY INTERVENTIONS IMPACT EXECUTIVE FUNCTION AND ACADEMIC PERFORMANCE IN CHILDREN AND ADOLESCENTS? A SYSTEMATIC REVIEW, META-ANALYSIS, AND META-REGRESSION

4.1 Introduction

The association between poor cardiorespiratory fitness (CRF) and a cluster of metabolic risk factors in children and adolescents has been well-described previously (Ortega et al., 2008a; Ruiz et al., 2006b). Despite there being a strong genetic component of CRF, and habitual physical activity (PA) not being related to CRF (Armstrong, Tomkinson & Ekelund, 2011), moderate to vigorous PA (MVPA) has been found to influence CRF (Ortega et al., 2008b). Indeed, recent work suggests that compared to merely replacing sedentary time with light or moderate PA, vigorous PA has a greater association with CRF both cross-sectionally and prospectively (Santos et al., 2018). Further, randomised controlled trials (RCTs) in school-aged children have demonstrated that increasing PA increases CRF (Eather, Morgan & Lubans, 2013), regardless of whether the PA is structured or un-structured (Sharma et al., 2017), although structured PA was found to be more beneficial (Sharma et al., 2017). Yet, a recent systematic review and meta-analysis found that PA interventions targeting adolescents have been largely unsuccessful, especially with older adolescents (Borde et al., 2017).

The academic training of children and adolescents is, for the majority, the responsibility of the educational system. Academic performance is defined as a domain that refers to the extent to which a student achieves their educational goals (Donnelly et al., 2016). The academic performance of pupils is typically measured through the assessments of their knowledge and scholastic aptitude in various subjects, of which mathematics and literacy are the most prominent (Singh et al., 2018; The Organisation for Economic Co-operation and Development, 2015). There is pressure on schools to perform better academically in these subjects, which can lead to less emphasis being spent on other subjects such as Physical Education (PE; Coe et al., 2006; Tsai et al., 2009; Arnold et al., 2016). This is despite the fact that emerging evidence has begun to link PA and CRF to both academic performance and executive function (Santana et al., 2017; Donnelly et al., 2016).

Executive function can be defined as a group of mental processes that are required when you have to pay attention or concentrate on a task (Diamond, 2013). These are needed when relying upon instinct would be ill-advised, insufficient, or impossible (Burgess & Simons, 2005; Epsy, 2004; Miller & Cohen, 2001). There is a general agreement in the literature that there are three sub-domains of executive function: inhibition, working memory, and cognitive flexibility (Lehto et al., 2003). Inhibition involves being able to control attention, behaviour, thoughts, and emotions to override internal instinct and do what is required or appropriate (Diamond, 2013). Working memory involves holding information in one's mind and mentally working with it (Baddeley & Hitch, 1994; Smith & Jonides, 1999). Cognitive flexibility builds on the other two sub-domains and involves a person being able to change how they think about something and also if they can change their perspectives both spatially and interpersonally (Diamond, 2013). The three sub-domains of executive function have been found to be individually associated with academic performance in children (St Clair-Thompson & Gathercole, 2006), and adolescents (Gathercole et al., 2004). These sub-domains also build higher-order executive functions such as reasoning, problem-solving and planning (Lunt et al., 2012;

Collins & Koechlin, 2012), which are important for many aspects of life, including mental health, physical health, school success, job success, and social and psychological development (Diamond, 2013). Executive function has been found to be associated with academic performance (Haile et al., 2016), classroom behaviours (Singh et al., 2012), and mental health (Diamond & Ling, 2016). Executive function has also been shown to be positively correlated with an increase in on-task behaviour (the amount of time spent working on a learning task), as well as improving the ability to inhibit off-task behaviour whilst in the classroom (Hofmann, Schmeichel & Baddeley, 2012).

The potentially positive effects of improving CRF, through increased PA, upon executive function may be explained by the cardiovascular fitness hypothesis. The cardiovascular fitness hypothesis suggests that CRF is a physiological mediator that explains various mental health benefits of PA (North, McCullagh & Tran, 1990). Indeed, building on this potential link between CRF and executive function, there have been numerous studies suggesting there is a positive association between CRF and academic performance (Bezold et al., 2014; Wittberg, Northrup & Cottrell, 2012). As such, it could be hypothesised that improving CRF, through increased PA, could lead to improvements in how children perform academically. This would be in addition to the other physical and mental health benefits children would receive from PA and improved CRF including reduced metabolic risk factors (Ruiz et al., 2007b), skeletal and muscle development (Ortega et al., 2008a), and improved self-perception and moods (Strong et al., 2005).

In the last decade there has been a growing interest into the possible relationship between CRF with academic performance and executive function in children and youth, and this has been reported in several types of reviews and meta-analyses (Haapala, 2013; Keeley & Fox, 2009; Santana et al., 2017; Donnelly et al., 2016; Marques et al., 2018; Álvarez-

Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018; Álvarez-Bueno et al., 2020). Two narrative reviews described research reporting a positive association between academic performance, executive function and CRF (Haapala, 2013; Keeley & Fox, 2009). There have been three systematic reviews recently published (Santana et al., 2017; Donnelly et al., 2016; Marques et al., 2018). These reviews all reported that studies suggest positive associations between CRF and PA with executive function and academic performance, although the findings were inconsistent, and the majority of studies included used a cross-sectional design. Recently there have been four meta-analyses published (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018; Ávarez-Bueno et al., 2020) reporting the effects of CRF/PA upon the sub-domains of executive function and several aspects of academic performance. The meta-analyses by Álvarez-Bueno et al. (2017a), Álvarez-Bueno et al. (2017b) and de Greeff et al. (2018) found small significant effects in the intervention groups for executive function and academic performance. A meta-analysis by Álvarez-Bueno et al. (2020) found that CRF was positively associated with academic performance. However, these recent meta-analyses primarily focused, although not exclusively, on cross-sectional associations between CRF/PA and executive function/academic performance instead of intervention studies (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018; Álvarez-Bueno et al., 2020). Further, it is typically assumed that PA interventions have induced improved CRF, although there is only moderate evidence for this in school-based interventions (Pozuelo-Carrascosa et al., 2018). Therefore, it is similarly assumed in accordance with cross-sectional data linking CRF and executive function or academic performance, that a mechanism may be involved in their improvement.

To date, and to the best of the thesis author's knowledge, there has not been investigation of studies that examined the association of changes in CRF with changes in executive function or academic performance resulting from PA interventions. Therefore, the aim of this study was to perform a systematic review, and accompanying meta-analysis and meta-regression, to investigate association of changes in CRF following a PA intervention with changes in executive function and academic performance.

4.2 Methods

This research was developed, performed, and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Liberati et al., 2009; Moher et al., 2012). A research protocol was developed and registered with the PROSPERO International prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO/), registration number CRD42017070845.

4.2.1 Literature Search

4.2.1.1 Eligibility Criteria

The primary source of articles in this meta-analysis were peer-reviewed journal articles published in the English language. An electronic search of the literature was conducted using combinations of the search terms below. Only intervention studies were included in this study and they had to include a control group. Studies were eligible if data were presented on CRF and executive function or academic performance at pre- and post-intervention.

4.2.1.2 Information Sources

Potential articles were identified by searching electronic databases and relevant article reference lists. The reference list of previous review articles was also screened. First, seven electronic databases were systematically searched: Medline/PubMed (EBSCOhost), Science Direct (Elsevier ScienceDirect), Scopus (Scopus), SPORTDiscus (SPORTDiscus), Academic Search Complete, CINAHL Complete, and PsychINFO. The last search was performed on the 10th October 2020. The search was developed and performed by the thesis author.

4.2.1.3 Search Strategy

Potential articles were identified in each of the databases (Medline/PubMed, Science Direct, Scopus, SPORTDiscus, Academic Search Complete, CINAHL Complete, and PsychINFO) by using search terms that had been developed through discussion within the research team. Search strategies included the combination between three groups of key-words/terms including the following: (a) CRF ("fitness," or "cardiorespiratory fitness," or "cardiovascular fitness," or "cardiovascular capacity," or "physical fitness," or "aerobic fitness," or "aerobic capacity,"); (b) academic performance ("academic outcome," or "academic performance," or "academic success," or "academic achievement," or "cognition," or "cognitive function," or "executive function"); (c) children/adolescents ("children," or "adolescents," or "teen," or "school-aged," or "youth"). An example of the search strategy is included in Table 4.1.

Table 4. 1 Literature search strategy

Cardiorespiratory fitness	Academic Performance / Executive Function	Study Population	Database searched
"(AB ("fitness" or "cardiorespiratory fitness" or "cardiovascular fitness" or "cardiovascular capacity" or "cardiovascular performance" or "physical fitness" or "aerobic fitness" or "aerobic capacity"))" OR "(TI ("fitness" or "cardiorespiratory fitness" or "cardiovascular fitness" or "cardiovascular capacity" or "cardiovascular performance" or "physical fitness" or "aerobic fitness" or "aerobic capacity"))"	"(AB ("academic performance" or "academic outcomes" or "academic success" or "academic achievement" or "behavio*" or "engagement" or "productivity" or "cogniti*" or "cognitive function" or "executive function"))" OR "(TI ("academic performance" or "academic outcomes" or "academic success" or "academic achievement" or "behavio*" or "engagement" or "productivity" or "cogniti*" or "cognitive function" or "executive function"))"	"(AB ("child*" or "adolescen*" or "teen*" or "school-aged" or "youth")) OR "(TI ("child*" or "adolescen*" or "teen*" or "school-aged" or "youth"))"	Medline/PubMed, Science Direct, Scopus, SPORTDiscus, Academic Search Complete, CINAHL Complete, PsychINFO

The literature search, the evaluation of the quality, and the extraction of the data were carried out independently by the thesis author and a second reviewer. Articles that were not relevant for the aim of the study were eliminated once the title was examined. Articles that were potentially eligible were analysed in their abstract following the inclusion and exclusion criteria. Disagreements between reviewers were resolved by consensus opinion or arbitration by a third reviewer. Furthermore, reference lists of selected articles and review articles were examined to identify more potential studies. Only original articles were included, and authors were contacted via email if full articles were not available or to request additional data if it was not reported in the final manuscript (i.e. to facilitate effect size calculations).

4.2.2 Inclusion and Exclusion Criteria

4.2.2.1 Type of Participants

Included studies' participants needed to be apparently healthy (i.e., free from known disease, disability [including learning disabilities], or injury) children and adolescents with a mean age between 5-18 years old. Studies with participants from any country, and studies focussing on a single sex or both were also included.

4.2.2.2 Types of Studies

The aim of this meta-analysis and meta-regression was to examine the evidence of how changes in CRF as a result of a PA intervention relate to changes in executive function or academic performance. Therefore, studies that only measured or reported CRF at baseline and did not report CRF at the end of the study or post-intervention were excluded. The meta-analysis included randomised controlled trials (RCTs) and non-RCTs that were written in English. Uncontrolled and cross-sectional studies were excluded from the analyses.

4.2.2.3 Types of Outcome Measures

Studies were included in the meta-analysis if they included both a pre- and a post-intervention measure of CRF as an outcome, in addition to an executive function outcome and/or an academic performance outcome. CRF measures could include the following; maximum oxygen uptake ($\dot{V}O_{2max}$) or peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) in a maximal graded fitness test on a treadmill or cycle ergometer, indirect measurement of $\dot{V}O_{2peak}$ in a maximal graded fitness test on a treadmill or cycle ergometer, or maximal field based CRF tests (e.g. 20m Multistage Shuttle Run (20mMSR)). An executive function outcome could include pre- and post-intervention measures of any of the sub-domains of executive functions (inhibition, working memory, or cognitive flexibility), a combination of the three, or all three sub-domains of executive functions. Sub-domains of academic performance include the different subjects that are taught in a school's curricular programme e.g. reading, mathematics, or languages. These can be measured by numerous standardised or non-standardised methods, including specific tests (e.g. for reading, language, or arithmetic skills etc.), a cluster of achievement tests, or grade point averages (Donnelly et al., 2016).

4.2.2.4 Exclusion Criteria

Articles published in non-English language were excluded. Articles that did not meet the inclusion criteria or did not include findings related to the inclusion criteria were excluded; e.g. a study measured CRF but did not also include a measure of executive function or an academic performance outcome. There were numerous studies that administered a PA intervention and examined the effects of an increase in PA on executive function or academic performance (Chaddock et al., 2012; Howie, Schatz & Pate, 2015). Many of these studies used a measure of CRF as a marker of health, although sometimes this was only measured or reported at baseline (Chaddock et al., 2012; Howie, Schatz & Pate, 2015). As noted, these studies were excluded as it would not allow the measurement of changes in CRF.

4.2.3 Data Extraction

The following data were extracted from all included articles following the Cochrane Consumers and Communication Review Group: (a) author, year of publication, and length of intervention (b) study design and location, (c) sample size and participant characteristics (including age at baseline and sex), (d) measurement tool for CRF, (e) measurement tool for executive function or academic performance, (f) controlled variables, (g) main findings, and (h) pre- and post-test means and standard deviations for CRF variable and academic performance/executive function variable.

4.2.4 Study Quality and Risk of Bias

The quality of the studies was assessed independently by the thesis author and a second researcher using two scales. The methodological quality and internal validity of RCTs were assessed using the Jadad Scale (Jadad et al., 1996), whilst non-RCTs were assessed using the Effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies (Armijo-Olivo et al., 2012). The Jadad Scale evaluates randomisation, blinding, and withdrawals/dropouts. A study can score between 0 and 5 points in total, where withdrawals/dropouts can score 1 point, and randomisation and blinding can score up to 2 points each. As PA interventions cannot be blinded to participants, a study could score two points if the assessors were blinded appropriately. The EPHPP Quality Assessment Tool for Quantitative Studies measures the methodological quality of studies in seven areas; selection bias, study design, confounders, blinding, data collection methods, and withdrawals/dropouts. Each of these items are rated as “Strong”, “Moderate”, or “Weak”. Studies are then rated as “Strong” (no weak ratings), “Moderate” (1 weak rating), or “Weak” (2 or more weak ratings).

4.2.5 Statistical Analyses

All analysis was performed using the ‘metafor’ package in R (version 3.5.1; R Core Development Team, https://www.r-project.org/). The difference in standardised mean changes for raw scores (pre- to post-intervention) were compared between groups using Hedges *g* and pre-test standard deviations used as the denominator (Morris, 2008). The magnitude of Hedges *g* were interpreted with reference to Cohen’s (1988) thresholds; trivial (< 0.2), small (0.2 to < 0.5), moderate (0.5 to < 0.8) and large (> 0.8) and positive effect size values indicated higher scores of the outcome in favour of the intervention group. Three separate random effects meta-analyses were performed to examine the effect of PA interventions upon CRF, executive function and academic performance generating point estimates for pooled effect sizes and precision of those estimates using 95% confidence intervals (CIs). Multilevel models with cluster robust estimates were used where multiple effect sizes were derived from the same studies and study groups with both included as random effects. Estimates were thus weighted by inverse sampling variance to account for this in addition to the between-studies variance (tau-squared), and restricted maximal likelihood estimation was used in all models. Executive function was also divided into three sub-domains; inhibition, working memory, and cognitive flexibility. Due to the limited number of studies academic performance was not divided into sub-groups.

Some further statistical information also needs to be explained. Firstly, there were a few studies that collected data over multiple time-points, if they collected data over a period of two or more years with data collection annually then the data collected at the end of year 1 was used. This reduced the variance in study length. Secondly, if a study had two intervention groups then their data were analysed independently with the control group thus yielding multiple effect sizes for that study and outcome.

Mixed-effect meta-regression analyses were carried out on the main effects of executive function and academic performance outcomes where the amount of change in CRF (Hedges *g* for CRF outcomes) between pre- and post-intervention was used as a moderator in order to examine the association of changes in CRF between intervention and control groups with changes in executive function and academic performance outcomes. Due to the range in age of the participants and length of the interventions exploratory moderation analyses were also performed examining age and the length of intervention. Additionally, sub group comparisons were performed to compare studies where PA intervention took up time in the curriculum that would be used for other academic subjects (Yes v No). A fixed-effects with moderators model was used to compare the two groups of studies to see if there was a significant difference between each set of the two models ($p < 0.05$). Influence analyses were performed examining Cook's distances for the main models of CRF, executive function and academic performance and where there was evidence of influential effect sizes (Cook's *d* ~1.0) models were rerun dropping that effect. Furthermore, heterogeneity was examined through the *Q* statistic and the I^2 statistic (Higgins et al., 2003). The *Q* statistic assesses the statistical significance of the variability of effects within and between study groups, a significant Q statistic suggests that studies are likely not drawn from a common population. The I^2 statistic provides an estimate of the degree of heterogeneity in effects among a set of studies from 0% to 100%. As a rough guide, I^2 values of 0% to 40% were not important, 30% to 60% moderate heterogeneity, 50% to 90% substantial heterogeneity, and 75% to 100% considerable heterogeneity (Higgins & Green, 2011). If the I^2 statistic is between two categories (e.g. 55%) then the heterogeneity would be reported as moderate to substantial. Risk of publication bias was examined graphically by contour enhanced funnel plots.

4.3 Results

4.3.1 Final Study Selection

The initial search identified a total of 8,430 potential papers, with three additional studies identified from reference lists of review articles. After adjusting for duplicates, 6,757 remained. Of these, 6,477 did not meet the criteria after screening the titles. Abstracts of 280 papers were examined and 128 articles remained. Full texts of these papers were reviewed. Of these studies, 111 did not meet the inclusion criteria: 78 of these studies did not have a control group, four studies appeared eligible but the authors did not respond or could not provide the additional required data that were requested, 18 studies did not have both pre- and post-intervention measures of CRF, six studies did not have both pre- and post-intervention measures of executive function or academic performance, two studies were cross-sectional designs, two studies had participants who were either too young or too old, and one study only did one bout of activity. Therefore, a final total of 17 studies were included in this meta-analysis (Figure 4.1).

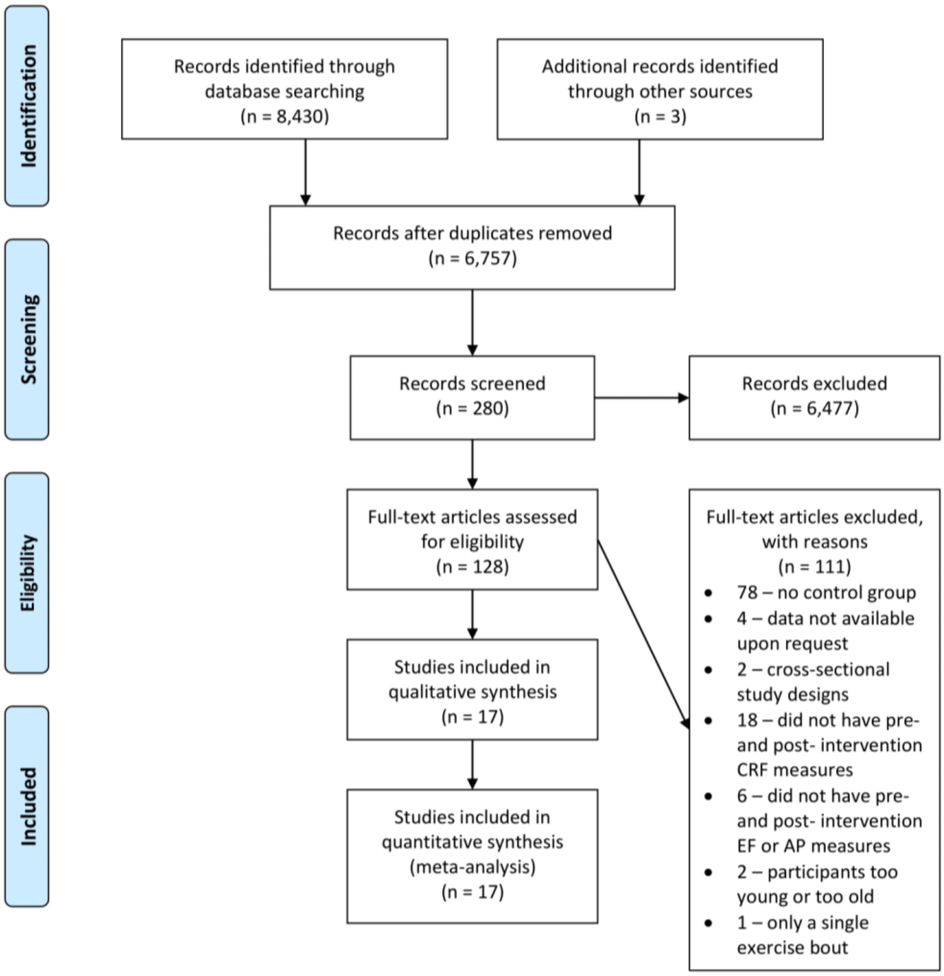

Figure 4. 1 PRISMA flow diagram

4.3.2 Systematic Review

The 17 studies included in the systematic review are shown in Tables 4.2 and 4.3. Nine examined the effects of a PA intervention on changes in CRF and executive function (van der Niet et al., 2016; Chaddock-Heyman et al., 2013; Crova et al., 2014; de Greeff et al., 2016; Hillman et al., 2014; Kamijo et al., 2011; Kvalø et al., 2017; Schmidt et al., 2015; van den Berg et al., 2019). Three studies measured the effects of a PA intervention on changes in CRF and academic performance (Donnelly et al., 2017; Garst et al., 2020; Weiss, Phillips & Kipp, 2015). The final five studies investigated the effects of a PA intervention on changes in CRF, and both academic performance and executive function (Gall et al., 2018; Garcia-Hermosa et al., 2020; Sjöwall, Hertz & Klingberg, 2017; Tarp et al., 2016; Torbeyns et al., 2017).

4.3.2.1 Participants

A total of 5,886 children and adolescents took part in the included studies. The sample size for individual studies ranged from 23 to 1,076 students. Participants' mean age ranged from 6 to 15 years old. Some studies recorded age, whilst others only recorded the school grades of the students from which age was inferred. All the studies used participants from both sexes. The number of studies from each country included in the review were: US (6), Netherlands (4), Denmark (1), South Africa (1), Switzerland (1), Norway (1), Sweden (1), Chile (1) and Italy (1). Fourteen of the studies were RCTs, and three used a quasi-experimental design.

4.3.2.2 Results of Studies Investigating Cardiorespiratory Fitness and Executive Function

Fourteen of the seventeen studies in this systematic review used a PA intervention to examine its effect on executive function (van der Niet et al., 2016; Chaddock-Heyman et al., 2013; Crova et al., 2014; de Greeff et al., 2016; Hillman et al., 2014; Kamijo et al., 2011; Kvalø et al., 2017; Schmidt et al., 2015; van den Berg et al., 2019 Gall et al., 2018; Sjöwall, Hertz & Klingberg, 2017; Tarp et al., 2016; Torbeyns et al., 2017; Garcia-Hermosa et al., 2020). Six of the fourteen studies found significant improvements in both CRF *and* executive function after the PA intervention compared with the controls (Chaddock-Heyman et al., 2013; Crova et al., 2014; Hillman et al., 2014; Kamijo et al., 2011; Schmidt et al., 2015; Gall et al., 2018). Six studies found a significant improvement in executive function after a PA intervention including inhibition (Chaddock-Heyman et al., 2013; Crova et al., 2014; Hillman et al., 2014; Gall et al., 2018), cognitive flexibility (Hillman et al., 2014; Schmidt et al., 2015) and working memory (Kamijo et al., 2011). One study found that the PA intervention significantly improved CRF compared to the control group in girls but not boys, and that there was no intervention effect on the executive function (Tarp et al., 2016). Three studies found that the PA intervention had a significant positive effect on CRF but there was no effect on executive function (Sjöwall, Hertz & Klingberg, 2017; Torbeyns et al., 2017; Garcia-Hermosa et al., 2020). One study found that there were no significant improvements in CRF for either the experimental and control groups (van der Niet et al., 2016). However, van der Niet et al. (2016) found that the experimental group improved their inhibition and working memory significantly in comparison to the control group. Three of the fourteen studies found that there was no significant effect of the PA intervention on CRF or executive function (de Greeff et al., 2016; Kvalø et al., 2017; van den Berg et al., 2019).

4.3.2.3 Results of Studies Investigating Cardiorespiratory Fitness and Academic Performance

Eight studies included in this systematic review measured the effect of a PA intervention on changes in CRF and academic performance (Donnelly et al., 2017; Weiss, Phillips & Kipp, 2015; Gall et al., 2018; Sjöwall, Hertz & Klingberg, 2017; Tarp et al., 2016; Torbeyns et al., 2017; Garcia-Hermosa et al., 2020; Garst et al., 2020). One study found significant improvements in both CRF *and* academic performance after the PA interventions compared to the controls (Garcia-Hermosa et al., 2020).

The results of the effects of the PA intervention on CRF varied. Donnelly et al. (2017) found that there were no significant differences in CRF between the experimental and control groups. Five studies found that CRF improved significantly in the intervention groups in comparison to the control groups (Sjöwall, Hertz & Klingberg, 2017; Torbeyns et al., 2017; Weiss, Phillips & Kipp, 2015; Garst et al., 2020; Garcia-Hermosa et al., 2020). Tarp et al. (2016) found an intervention effect for CRF in girls but not boys, and Gall et al. (2018) found a small decrease in CRF in both groups. One of the eight studies also investigated the effects of an intervention on academic-related outcomes, including effort, classroom behaviour, tardiness, and absenteeism (Weiss, Phillips & Kipp, 2015). Weiss, Phillips and Kipp (2015) found that children who took part in the PA intervention had fewer absences compared to the control group. The effect of the PA intervention on academic performance also varied. One study found a positive intervention effect for academic performance, which was measured by a composite score of four curricular subjects (Gall et al., 2018). Another study found significant group-by-time interactions suggesting a reduction in academic performance for the intervention group compared to the control group (Garst et al., 2020). Mathematics was the subject measured by six of the eight studies. Mathematics improved from baseline to post-intervention in both the experimental and control groups, with no significant between-group differences in four studies (Donnelly et al., 2017; Weiss, Phillips & Kipp, 2015; Sjöwall, Hertz & Klingberg, 2017; Tarp et al., 2016). There was a significant decrease over time across all participants in mathematics reported by one study (Torbeyns et al., 2017) and an increase in the intervention group for another study (Garcia-Hermosa et al., 2020). Of the four studies that measured Reading as an individual subject, no intervention effect was found by three studies (Donnelly et al., 2017; Weiss, Phillips & Kipp, 2015; Torbeyns et al., 2017) and a positive intervention effect was found by one study (Garcia-Hermosa et al., 2020).

Table 4. 2 Study Characteristics and Results of Studies Investigating Cardiorespiratory Fitness and Executive Function

Reference	Location / Study Design / Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Executive Function	Control Variables	PA Intervention Details	Main Findings
Chaddock-Heyman et al. (2013)	US / RCT / 9 months	23 children / 8-9 years old / boys and girls	Maximal graded exercise test administered on a treadmill	Flanker task measured inhibition.	Body mass index (BMI), age, sex, pubertal timing, and socio-economic status (SES)	Non-curricular intervention. 5x120 minute sessions per week. Average 76.8 minutes of MVPA per session. Aerobic activities as well as muscle and bone strengthening activities were included through fitness activities and low-organised games.	60+ minutes of PA per day for 5 days per week decreases in fMRI brain activation in the right anterior prefrontal cortex coupled with within-group improvements in performance on a task for attentional and interference control.
Crova et al. (2014)	Italy / RCT / 6 months	70 children / 9-10 years old / boys and girls	20mMSR	Random number generator task measured inhibition and working memory.	BMI, age, sex, and baseline differences	Non-curricular intervention. 2x60 minute sessions of enhanced PE programme of skill based and tennis-specific training per week. Average 49.6% of sessions spent doing MVPA.	Children with higher CRF had higher inhibition and working memory than children with lower CRF.
de Greeff et al. (2016)	Netherlands / RCT / 2 years	499 children / 5-7 years old / 2nd-3rd grades / boys and girls	20mMSR	Stroop test measured inhibition. Digit span backward and Visual span measured working memory. Wisconsin card sorting test measured cognitive flexibility.	Grade and sex	Curricular intervention. 3x20-30 minute sessions per week. 60% of each lesson was spent in MVPA. Exercises were performed whilst solving an academic task.	There was no significant difference between the intervention and control groups for CRF or executive function.

Table 4.2. continued

Reference	Location / Study Design / Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Executive Function	Control Variables	PA Intervention Details	Main Findings
Gall et al. (2018)	South Africa / RCT / 20 weeks	663 children / 8-13 years old / boys and girls	20mMSR	Selective attention measured by d2 test.	Sex, stunting, anaemia, intestinal protozoa and soil-transmitted helminth infections, age, BMI, SES, self-reported PA, grip strength, and V̇O2max	Curricular intervention. The intervention included 2x45 minute PE lessons per week, 1x45 minute moving to music class per week, in-class activity breaks, and school infrastructure adaption.	No significant intervention effect found on selective attention. Children with higher CRF had better concentration performance than less fit peers.
Hillman et al. (2014)	US / RCT / 9 months	221 children / 7-9 years old / boys and girls	Maximal graded exercise test administered on a treadmill.	Flanker task measured inhibition. Switch task measured cognitive flexibility.	Sex and age	Non-curricular intervention. 5x120 minute sessions per week. >70 minutes of MVPA per session. Sessions were aerobically demanding with opportunities to refine motor skills.	The PA intervention enhanced executive function and brain function during tasks that required greater executive control.
Kamijo et al. (2011)	US / RCT / 9 months	43 children / 7-9 years old / boys and girls	Maximal graded exercise test administered on a treadmill.	Sternberg task measured working memory.	BMI, age, SES, ADHD scores, pubertal status, and IQ	Non-curricular intervention. 5x120 minute sessions per week. >70 minutes of MVPA per session. Sessions were aerobically demanding with opportunities to refine motor skills.	PA intervention led to increases in CRF and Sternberg task performance. The beneficial effects of the PA intervention were greater for task conditions that required greater working memory demands.
García-Hermoso et al. (2020)	Chile / Randomised controlled trial / 8 weeks	170 children / 8-10 years old / boys and girls	20mMSR	Attention capacity using the d2 Test of Attention	Baseline scores, age, sex, weight status, peak heigh velocity, sedentary time, moderate-vigorous physical activity levels, and school	Non-curricular intervention. Children attended five times per week before their first class (8:00-8:30 AM). Sessions included cooperative physical games in addition to age appropriate sports, playground games, dance, and other recreation.	Neither selective attention nor concentration improved significantly. Effects were trivial.

Table 4.2. continued

Reference	Location / Study Design /Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Executive Function	Control Variables	PA Intervention Details	Main Findings
Kvalø et al. (2017)	Norway / RCT / 6 months	449 children / 9-10 years old / boys and girls	20mMSR	Stroop test measured inhibition. Digit span test measured working memory. Trail Making Test measured cognitive flexibility.	Sex, BMI, and waist circumference	Curricular and non-curricular intervention. 2x45 minutes physically active lessons, 5x10 minute physically active homework, 5x10 minute PA during recess. No intensity reported.	Results indicate that increased physical activity in school might improve children's executive function, even without improvements in CRF.
Schmidt et al. (2015)	Switzerland / RCT / 6 weeks	181 children / 10-12 years old / boys and girls	20mMSR	Flanker task measured inhibition. An additional block of the flanker task was used to measure cognitive flexibility. The n-back task measured working memory.	Physical activity level, pubertal status, SES, BMI z-score, and academic performance	Curricular intervention. 2x45 minute sessions per week. Team Games intervention group: floorball and basketball tailored games to challenge executive function. Aerobic Exercise: aerobic exercise that were not cognitively engaging. PA intensities not specified.	The results showed that both the Team Games and Aerobic Exercise interventions improved CRF more than the control group. Only the Team Games intervention significantly improved children's cognitive flexibility performance, and the other two measurements of executive function remained unaffected.
Sjöwall, Hertz, and Klingberg (2017)	Sweden / Quasi-experimental design / 2 years	228 children / 6-13 years old / boys and girls	20mMSR	Arithmetic test	Sex and age	Curricular intervention. 3x40 minutes per week of additional PA. Various physical activities. Specified as high intensity but not measured.	No beneficial development of arithmetic for active school compared to control school.

Table 4.2. Continued

Reference	Location / Study Design /Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Executive Function	Control Variables	PA Intervention Details	Main Findings
Tarp et al. (2016)	Denmark / Cluster-randomised control trial / 20 weeks	632 children / 12-14 years old / boys and girls	Andersen Test	Flanker task measured inhibition.	Sex and age	Curricular and non-curricular intervention. 5x60 minutes extra PA over per week. 60 minutes could include class-room PA, structured recess PA, PA homework. Intensity was measured but no requirements were made.	No significant difference in change, when comparing the intervention and control groups in executive function. An intervention effect was found for CRF in girls.
Torbeyns et al. (2017)	Belgium / RCT / 5 months	44 children / 14 years old / boys and girls	20mMSR	Rey Auditory Verbal Learning Test to measure working memory. The Stroop test and the Rosvold Continuous Performance Test measured inhibition.	Age, BMI, body fat percentage, waist circumference	Curricular intervention. 4x50 minutes per week using a bike desk. Cycling intensity measured but not standardised.	No significant effect of using bike desk in classroom on executive function. CRF significantly improved in the intervention group.
van den Berg et al. (2019)	Netherlands / RCT / 9 weeks	512 children / 9-12 years old / boys and girls	20mMSR	d2 test of attention, fluency task, attention network task, Stroop task	Age and baseline score	Curricular intervention. 5x10 minute exercise break during class. Moderate to vigorous intensity. Accelerometers and heart rate was monitored and used to measure PA and exercise intensity.	No intervention effects on executive function or CRF.
van der Niet et al. (2016)	Netherlands / Quasi-experimental design / 22 weeks	105 children / 8-12 years old / boys and girls	20mMSR	Stroop test measured inhibition, visual memory and digit span tests measured working memory, trail making test measured cognitive flexibility and tower of London test measured planning.	Age, SES, sex, and baseline scores	Non-curricular intervention. 5x30 minutes lunchtime sessions per week. Moderate to vigorous activities including running games, circuit training, and cognitive PA. Heart rate was monitored to measure intensity.	CRF improved for children in both the intervention and control groups, but not significantly. Inhibition and working memory improved significantly in intervention group compared to control group. No other significant effects were found on the other executive functioning measures.

Table 4. 3 Study Characteristics and Results of Studies Investigating Cardiorespiratory Fitness and Academic Performance

Reference	Location / Study Design /Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Academic Performance	Control Variables	PA Intervention Details	Main Findings
Donnelly et al. (2017)	US / RCT / 3 years	584 children / 7-9 years old / 2nd-3rd grades / boys and girls	Progressive Aerobic Cardiovascular Endurance Run (PACER)	Wechsler Individual Achievement Test-Third Edition (WIAT-III) measured academic performance. Standardised composite scores for mathematics, reading comprehension fluency, and spelling.	Age, BMI, waist circumference, sex, ethnicity, annual household income, baseline differences.	Curricular intervention. 10x10 minute active lesson sessions per week. Activities aimed for 4-5 metabolic equivalents (METs) per session, but not measured.	Academic performance improved across 3 years in reading, mathematics, and spelling in children in intervention and control schools, with no significant between group differences.
Gall et al. (2018)	South Africa / RCT / 20 weeks	663 children / 8-13 years old / boys and girls	20mMSR	Composite average of end of year results from home language, additional language, mathematics, and life skills.	Sex, stunting, anaemia, age, BMI, SES, self-reported PA, grip strength, and V̇O2max	Curricular intervention. The intervention included 2x45 minute PE lessons per week, 1x45 minute moving to music class per week, in-class activity breaks, and school infrastructure adaption. Intensity not measured or specified.	PA intervention had positive effect on academic performance. After controlling for confounders, there was no change in academic performance for intervention group but a decrease in control group.
Garst et al., (2020)	US / Randomised controlled trial / 9 months	144 children / 11-14 years old / boys and girls	PACER	Average school reported grades at end of semester	Sex	Curricular interventions. The control group participated in regular PE. The intervention group replaced PE with a CrossFit workout. Both were performed three times a week for 60 minutes per session.	Significant group by time interactions were found suggesting a reduction in AP for the intervention group and maintenance in the control group
Sjöwall, Hertz, and Klingberg (2017)	Sweden / Quasi-experimental design / 2 years	228 children / 6-13 years old / boys and girls	20mMSR	Arithmetic test	Sex and age	Curricular intervention. 3x40 minutes per week of additional PA. Various physical activities. Specified as high intensity but not measured.	No beneficial development of arithmetic for active school compared to control school.
Torbeyns et al. (2017)	Belgium / RCT / 5 months	44 children / 14 years old / boys and girls	20mMSR	Standardised Dutch (native language) and mathematic tests.	Age, BMI, body fat percentage, waist circumference	Curricular intervention. 4x50 minutes per week using a bike desk. Cycling intensity measured but not standardised.	No significant effect of using bike desk in classroom on academic performance. CRF significantly improved in the intervention group.

Table 4.3. continued

Reference	Location / Study Design / Length of Study	Participants' Baseline Characteristics	Assessment of CRF	Assessment of Academic Performance	Control Variables	PA Intervention Details	Main Findings
Tarp et al. (2016)	Denmark / Cluster-randomised controlled trial / 20 weeks	632 children / 12-14 years old / 6-7th grades / boys and girls	Andersen Test	Academic performance measured using a custom-made grade specific mathematics test.	Sex, age, waist circumference, BMI, pubertal status, PA levels.	Curricular and non-curricular intervention. 5x60 minutes extra PA over per week. 60 minutes could include class-room PA, structured recess PA, PA homework. Intensity was measured but no requirements were made.	No significant difference in change, when comparing the intervention and control groups in mathematics. An intervention effect was found for CRF in girls.
Weiss, Phillips, and Kipp (2015)	US / Quasi-experimental design / 1 year	1076 children / 11-14 years old / 6th-8th grades / boys and girls	PACER	Standardised test score in mathematics and reading from previous and current year	Baseline differences in BMI, waist circumference, self-esteem, perceived physical confidence, perceived academic differences, and perceived peer acceptance	Curricular intervention. 2x45 minutes per week. Enhanced PE lessons focussing on moderate intensity activities. No measure of PA.	The results showed that the boys and girls in the intervention groups had significantly improved in CRF ($p < 0.05$) compared to the control group. Reading and mathematics test scores increased for both boys and girls in the intervention and control groups, although only the boys' control group's reading test score improved significantly ($p < 0.05$).
García-Hermoso et al. (2020)	Chile / Randomised controlled trial / 8 weeks	170 children / 8-10 years old / boys and girls	20mMSR	End of semester grades in mathematics and language	Baseline scores, age, sex, weight status, peak height velocity, sedentary time, moderate-vigorous physical activity levels, and school	Non-curricular intervention. Children attended five times per week before their first class (8:00-8:30 AM). Sessions included cooperative physical games in addition to age appropriate sports, playground games, dance, and other recreation.	Both language and mathematics grades improved significantly in the intervention group compared to the control group (who decreased) with moderate to large effects

4.3.3 Study Quality

The methodological quality and internal validity of the 14 RCT studies, shown in Table 4.4, assessed using the Jadad Scale (Jadad et al., 1996) varied: four studies scored two points (Chaddock-Heyman et al., 2013; Crova et al., 2013; Kamijo et al., 2011; Torbeyns et al., 2017), six studies scored three points (de Greeff et al., 2016; Kvalø et al., 2017; van den Berg et al., 2019; Gall et al., 2018; Tarp et al., 2016; Garst et al., 2020), two studies scored four points (Schmidt et al., 2015; Donnelly et al., 2017), and two studies scored five points (Hillman et al., 2014; Garcia-Hermosa et al., 2020). The methodological quality of two of the three quasi-experimental studies, shown in Table 4.5, that were assessed using the EPHPP Quality Assessment Tool for Quantitative Studies (Armijo-Olivo et al., 2012) were "Weak" (Weiss, Phillips & Kipp, 2015; Sjöwall, Hertz & Klingberg, 2017), and one study was rated as "Moderate" (van der Niet et al., 2016).

4.3.4 Publication Bias

Examination of the contour enhance funnel plots did not reveal any obvious publication bias (Figures 4.2). However, van der Niet et al. (2016) appeared to be an outlier when examining executive function which was also confirmed when examining Cook's *d* for executive function. For comparative purposes, results from meta-analyses and meta-regressions for executive function are reported both with and without the van der Niet et al. (2016) study included.

Table 4. 4 Study quality assessment of RCTs using Jadad scale

Study	Randomisation	Blinding	Dropout	Total
Chaddock-Heyman et al. (2013)	1	0	1	2
Crova et al. (2014)	1	0	1	2
de Greeff et al. (2016)	1	1	1	3
Donnelly et al. (2017)	2	2	0	4
Gall et al. (2018)	2	0	1	3
Garcia-Hermosa et al. (2020)	2	2	1	5
Garst et al. (2020)	2	0	1	3
Hillman et al. (2014)	2	2	1	5
Kamijo et al. (2011)	1	0	1	2
Kvalø et al. (2017)	2	0	1	3
Schmidt et al. (2015)	1	2	1	4
Tarp et al. (2016)	2	0	1	3
Torbeyns et al. (2017)	1	0	1	2
van den Berg et al. (2019)	2	0	1	3

Table 4. 5 Study quality assessment of non-RCTs using Quality Assessment Tool for Quantitative Studies

Study	A) Selection Bias	B) Study Design	C) Confounders	D) Blinding	E) Data Collection	F) Withdrawals & Dropouts	Total
Sjöwall, Hertz, and Klingberg (2017)	Moderate	Strong	Strong	Weak	Strong	Weak	Weak
Weiss, Phillips, and Kipp (2015)	Strong	Strong	Strong	Weak	Strong	Weak	Weak
van der Niet et al. (2016)	Strong	Strong	Strong	Weak	Strong	Strong	Moderate

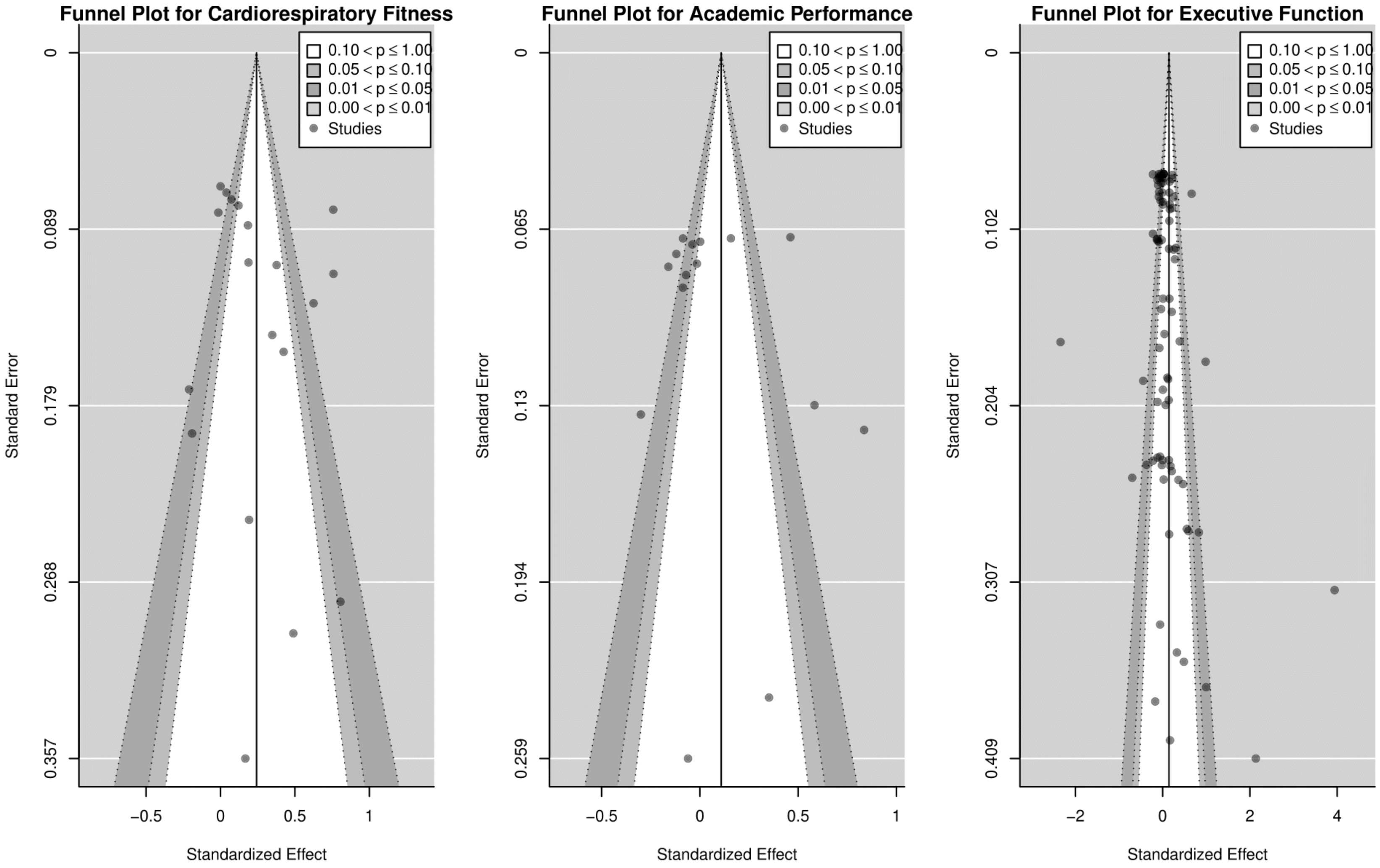

Figure 4. 2 Contour enhanced funnel plots

4.3.5 Meta-Analysis and Meta-Regression

4.3.5.1 Cardiorespiratory Fitness

The pooled effect size [95% CI] estimate for the effects of a PA intervention on CRF was 0.24 [95% CI = 0.09, 0.40] indicating a small effect, though with reasonable precision indicated by the CIs ranging from trivial to small (Figure 4.3). Cochrane's Q showed for overall CRF, a significant heterogeneity (Q = 131.26, df = 18, $p < 0.001$) and a substantial to considerable inconsistency measure with I^2 of 86.7%. The effect of age upon CRF outcomes was trivial (β = 0.01 [95% CI = -0.09, 0.07]; Figure 4.4), and the effect of intervention duration was essentially null (β = 0.00 [95% CI = -0.00, 0.00]; Figure 4.5). The effect of whether the intervention was during curriculum time was trivial for curricular interventions (ES = 0.18 [95% CI = -0.01, 0.37]), and small for non-curricular interventions (ES = 0.45 [95% CI = 0.09, 0.80]) but no significant difference between the two models was found (z = 1.718, p = 0.086).

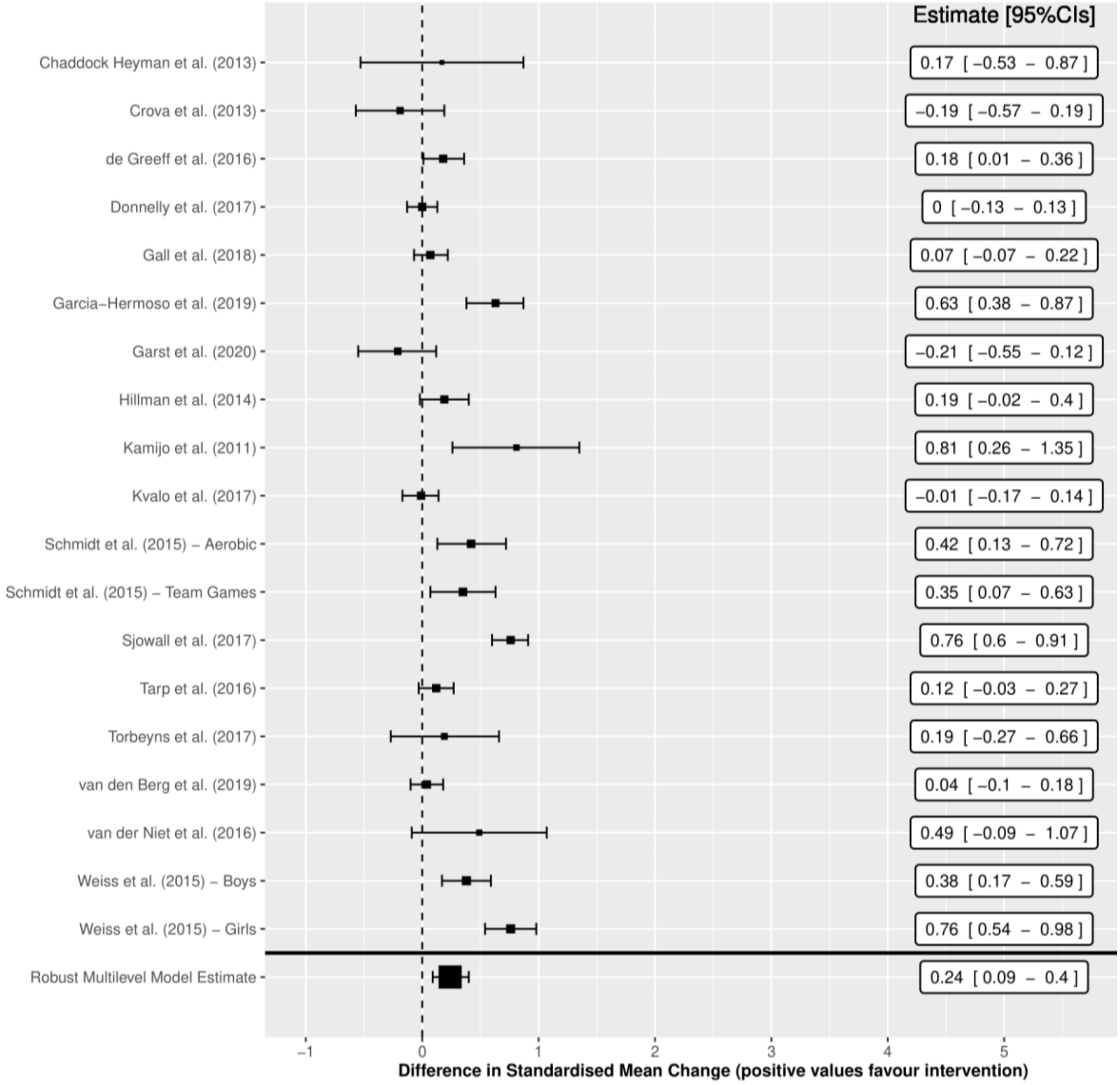

Figure 4. 3 Forest plot of cardiorespiratory fitness outcomes

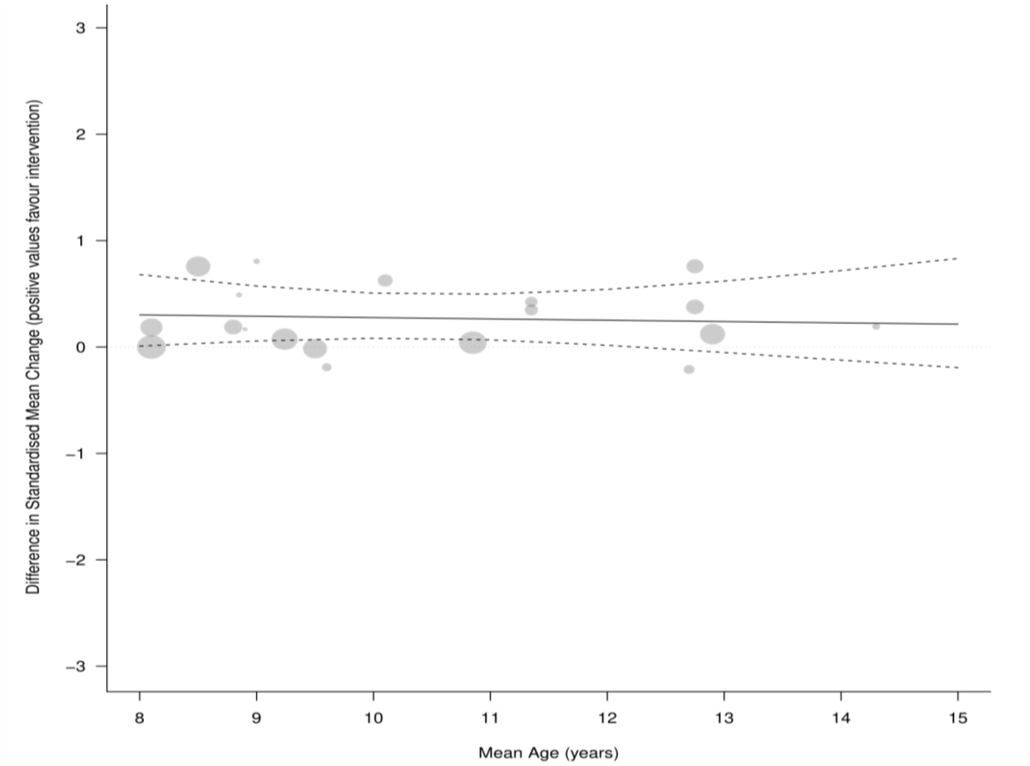

Figure 4. 4 Meta-analytic scatterplot for cardiorespiratory fitness and age

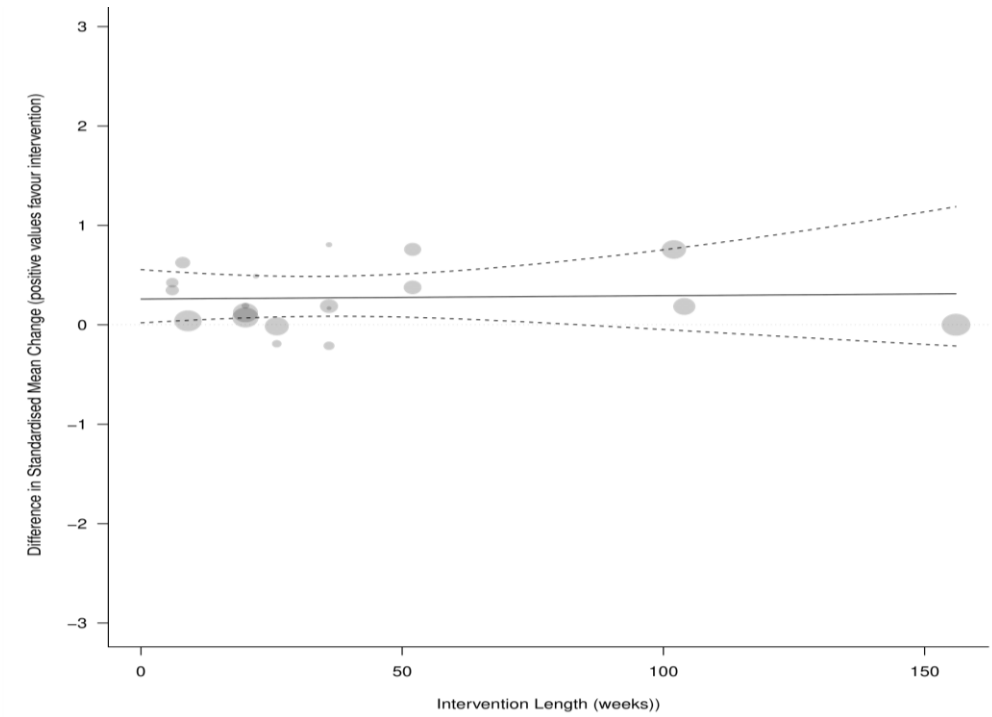

Figure 4. 5 Meta-analytic scatterplot for cardiorespiratory fitness and intervention length

4.3.5.2 Executive Function

The pooled effect size for overall executive function was 0.14 [95% CI = -0.12, 0.41] indicating a trivial effect with relatively low precision indicated by the CIs ranging from negative trivial to small. Due to the number of effects sizes in the executive function model these are represented as a caterpillar plot (Figure 4.6). Cochrane's Q showed for the overall executive function, a significant heterogeneity ($Q = 634.57$, df = 82; $p < 0.001$) and a considerable inconsistency measure with I^2 of 94.6%. The effect size estimates of the sub-domains of executive function were also calculated. Inhibition had an effect size estimate of 0.29 [95% CI = -0.32, 0.91] (Figure 4.7) indicating a small effect with relatively low precision indicated by the CIs ranging from negative small to large, with a significant heterogeneity ($Q = 446.94$, df = 52, $p < 0.001$), and a considerable inconsistency measure with I^2 of 92.5%. Working memory had an effect size estimate of 0.18 [95% CI = -0.10, 0.45] (Figure 4.8) indicating a trivial effect though with reasonable precision indicated by the CIs ranging from trivial to small, with a significant heterogeneity ($Q = 149.78$, df = 19, $p < 0.001$), and a considerable inconsistency measure with I^2 of 92.5%. Cognitive flexibility had an effect size estimate of 0.06 [95% CI = -0.13, 0.25] (Figure 4.9) indicating a trivial effect with reasonable precision indicated by the CIs ranging from negative trivial to trivial, with significant heterogeneity (Q =25.40, df = 9, $p < 0.001$), and a moderate to substantial inconsistency measure with I^2 of 56.3%. With the study of van der Niet et al. (2016) removed the pooled effect size for overall executive function was reduced to 0.02 [95% CI = -0.09, 0.13].

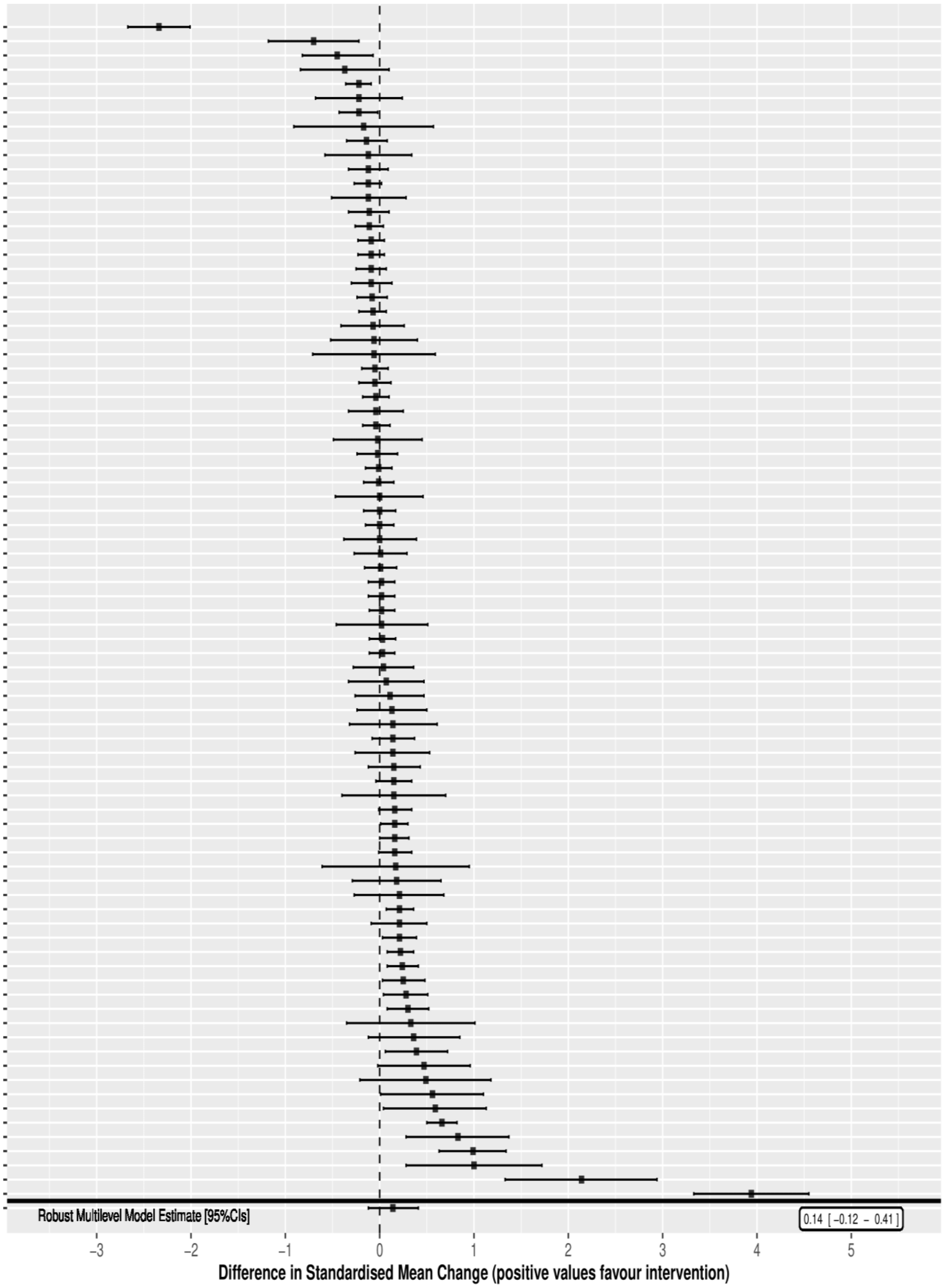

Figure 4. 6 Caterpillar plot of executive function outcomes

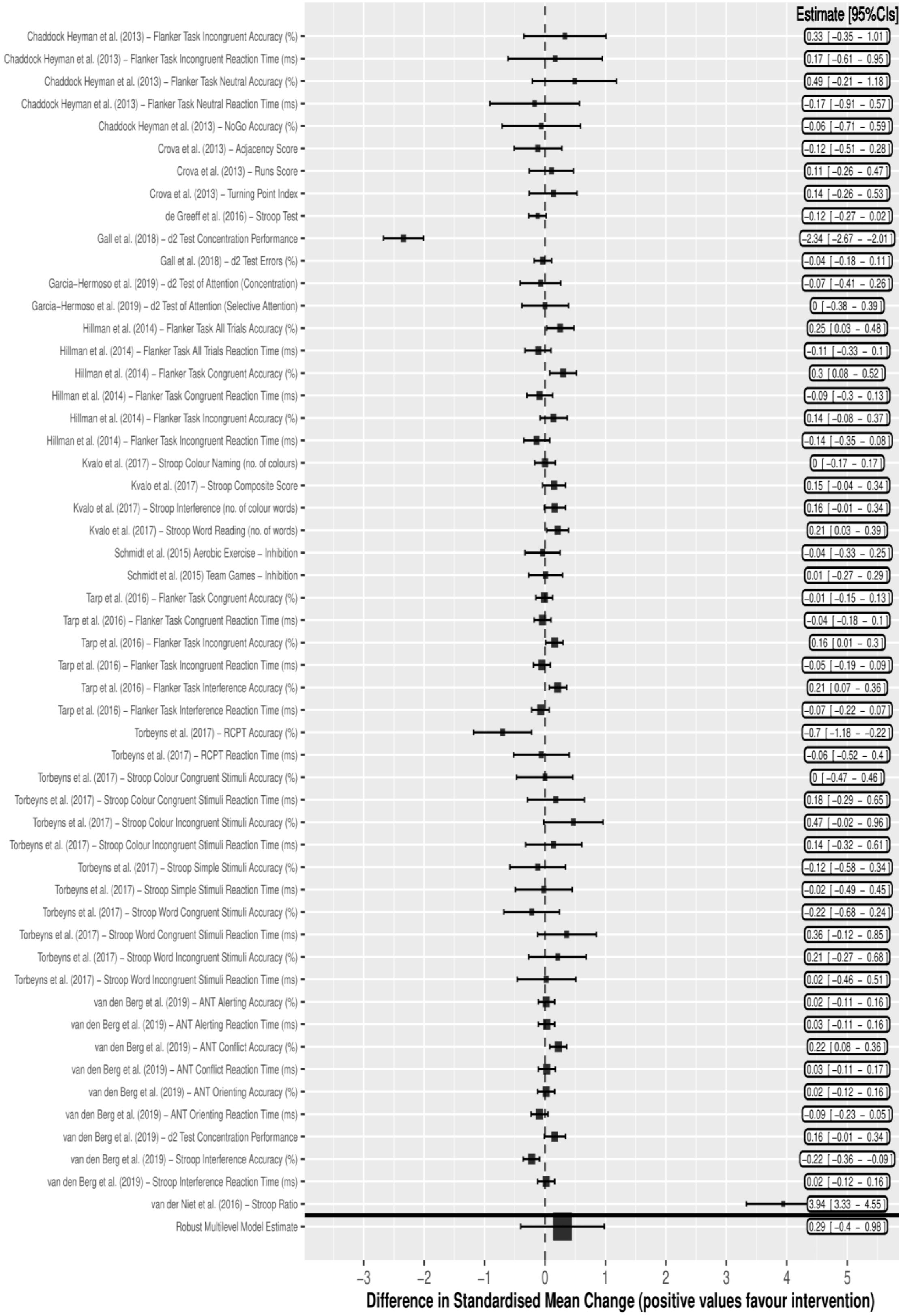

Figure 4. 7 Forest plot of inhibition outcomes

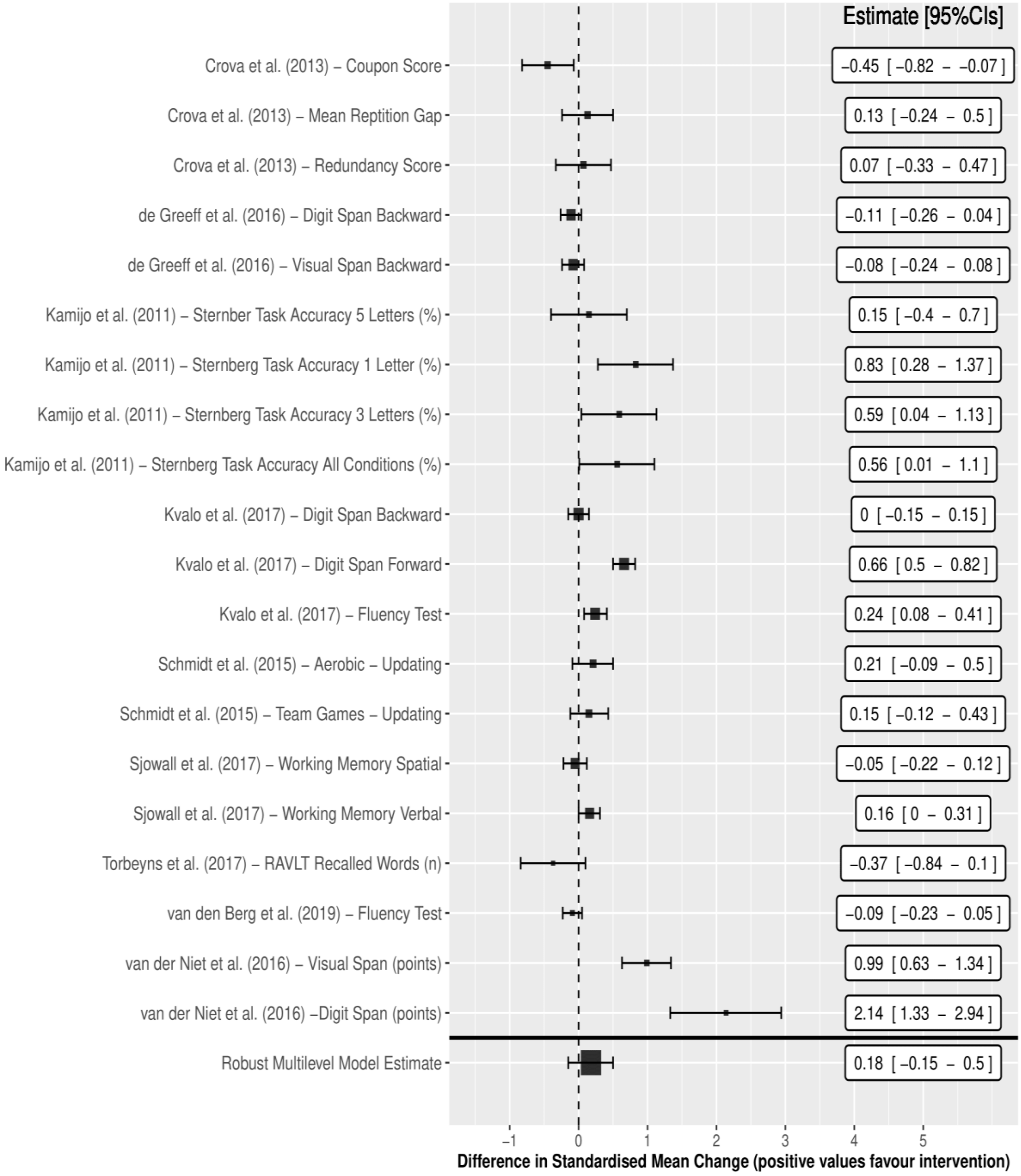

Figure 4. 8 Forest plot of working memory outcomes

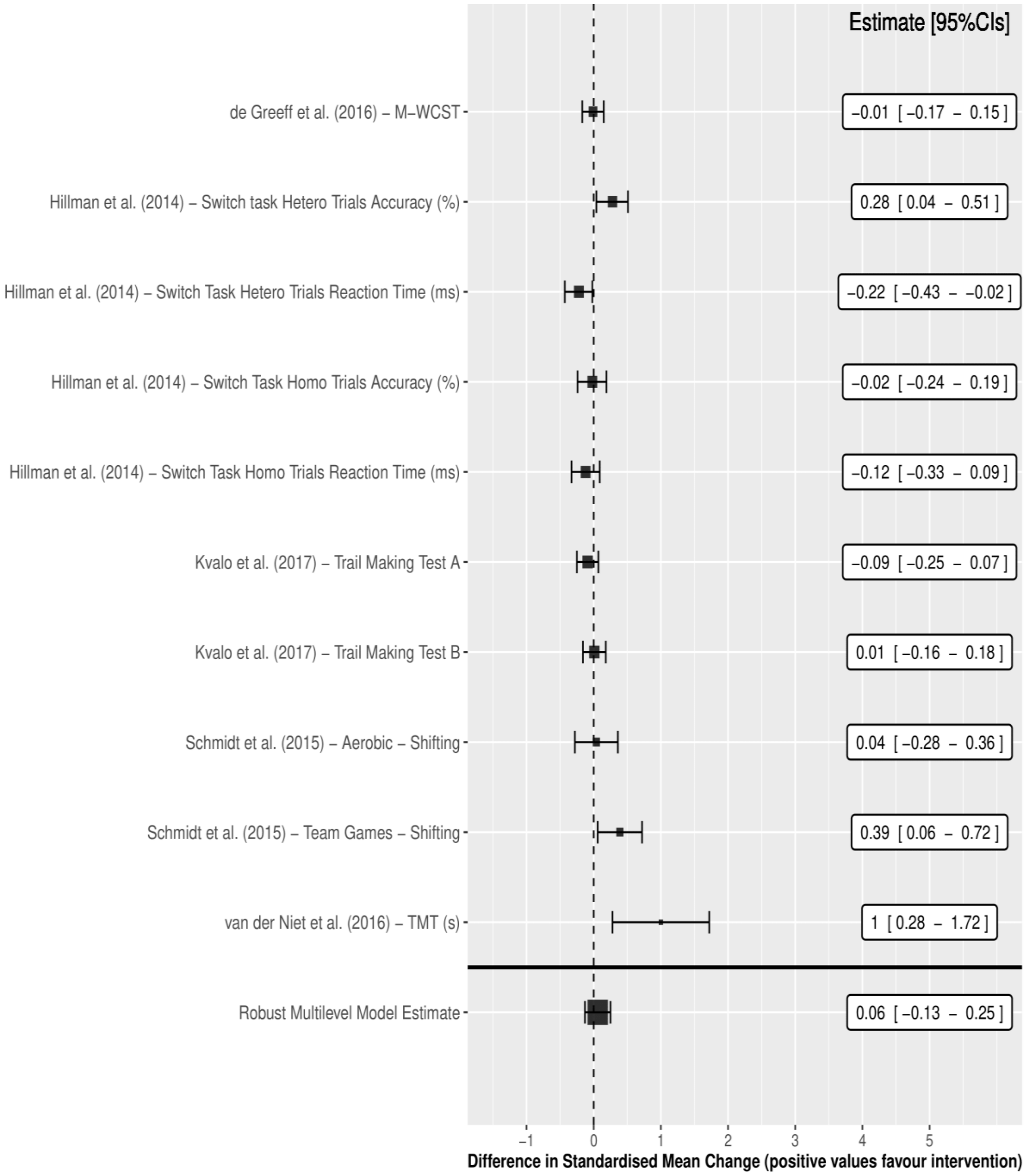

Figure 4. 9 Forest plot of cognitive flexibility outcomes

The effect of age upon executive function outcomes was trivial (β = -0.05 [95% CI = -0.15, 0.06]; Figure 4.10) and the effect of study duration was essentially null (β = 0.00 [95% CI = -0.01, 0.00]; Figure 4.11). The effect of whether the intervention was during curriculum time was trivial for curricular interventions (ES = -0.01 [95% CI = -0.13, 0.10]) and small for non-curricular interventions (ES = 0.45 [95% CI = -0.24, 1.15]) but no significant difference between the two models was found (z = 1.825, p = 0.06). These models were also rerun excluding van der Niet et al. (2016). The effect of age upon executive function outcomes after the study by van der Niet et al. (2016) was removed became essentially null (β = 0.00 [95% CI = -0.04, 0.04]) and the effect of study duration remained essentially null (β = 0.00 [95% CI = 0.00, 0.00]). After the study by van der Niet et al. (2016) was removed the effect of whether the intervention was during curriculum time was trivial for curricular interventions (ES = -0.01 [95% CI = -0.13, 0.10]) and small for non-curricular interventions (ES = 0.21 [95% CI = -0.24, 1.15]) but no significant difference between the two models was found (z = 1.866, p = 0.06). The effect of CRF effects upon executive function outcomes was moderate (β = 0.51 [95% CI = -0.27, 1.29]) with very poor precision ranging from negative small to positive large effects. The meta-analytic scatterplot of CRF effects upon EF outcomes is shown in Figure 4.12. With the study of van der Niet et al. (2016) removed the estimated effect decreases in magnitude and increased in precision (β = 0.26 [95% CI = -0.18, 0.70]) suggesting a small effect ranging from a possible negative trivial to moderate effect. However, this still included a possible effect estimate of zero.

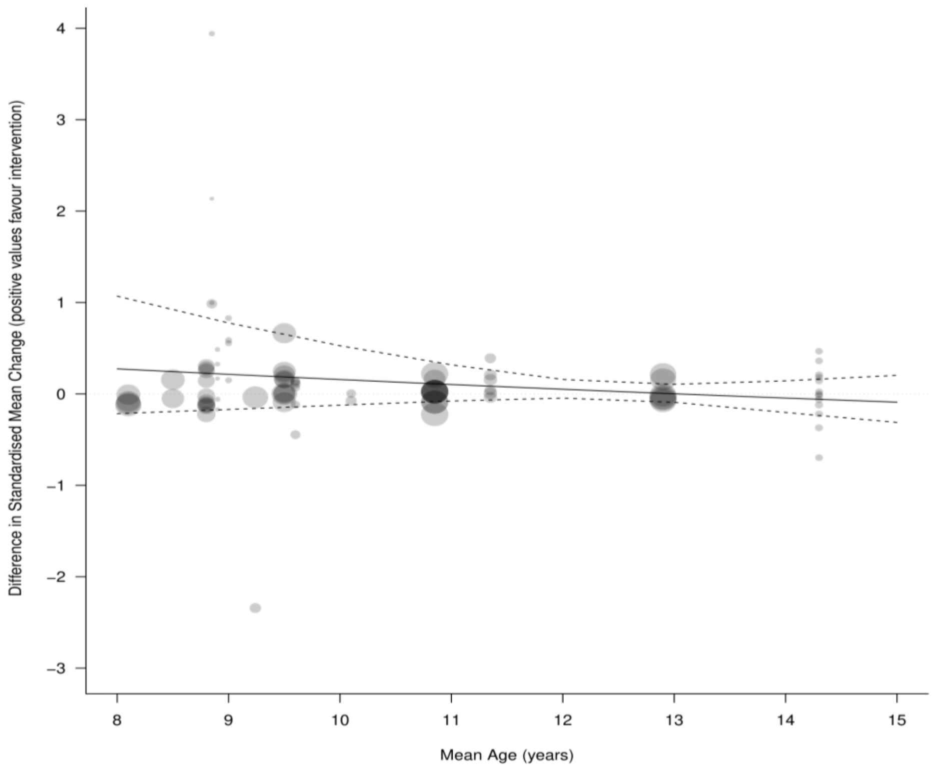

Figure 4. 10 Meta-analytic scatterplot of executive function and age

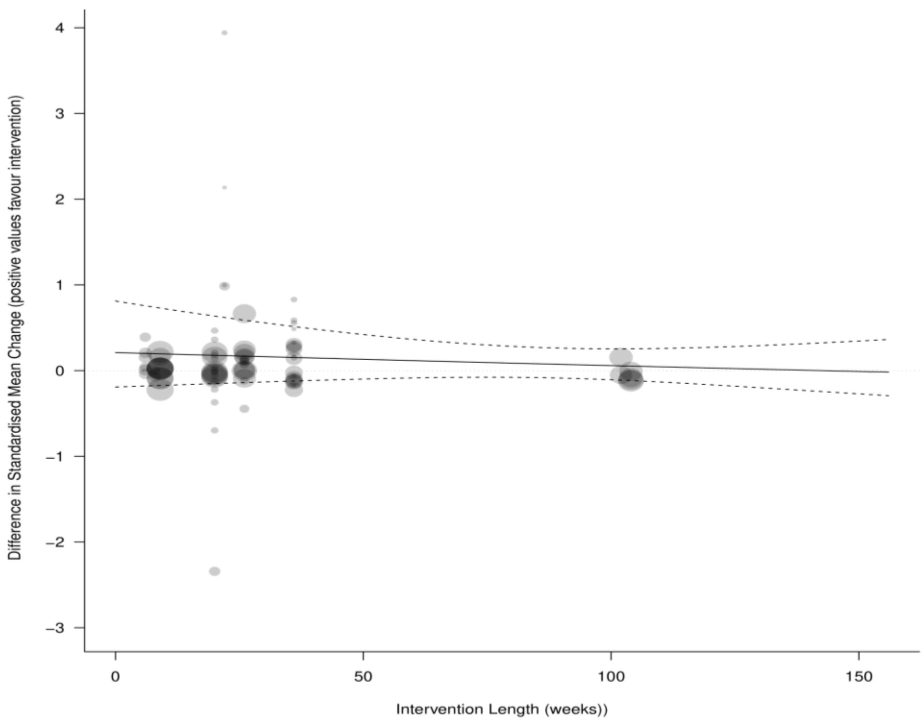

Figure 4. 11 Meta-analytic scatterplot of executive function and intervention length

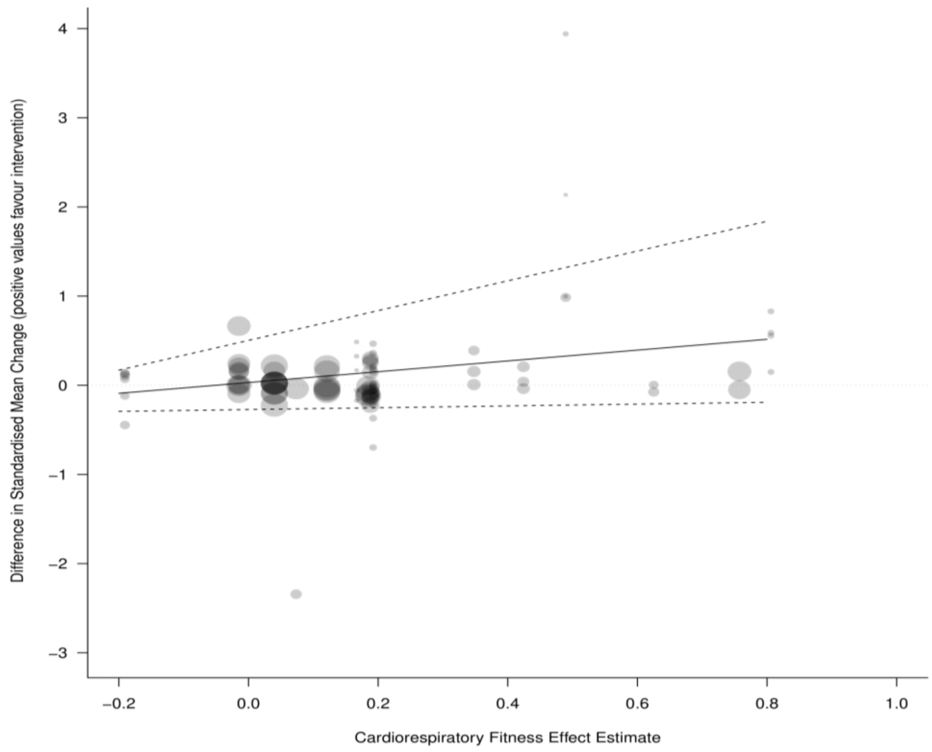

Figure 4. 12 Meta-analytic scatterplot of executive function and cardiorespiratory fitness

4.3.5.3 Academic Performance

For academic performance, the pooled effect size estimate was 0.11 [95% CI = -0.16, 0.38] (Figure 4.13), indicating a trivial effect with reasonable precision indicated by the CIs ranging from negative trivial to small. Cochrane's *Q* showed for the overall academic performance, a significant heterogeneity (Q = 120.89, df = 14; $p < 0.001$) and a considerable inconsistency measure with I^2 of 69.9%. The effect of age upon academic performance outcomes was trivial (β = -0.04 [95% CI = -0.14, 0.07]; Figure 4.14), and the effect of study duration was essentially null (β = 0.00 [95% CI = -0.01, 0.00]; Figure 4.15). The effect of whether the intervention was during curriculum time was trivial for curricular interventions (ES = 0.05 [95% CI = -0.22, 0.32]), and small for non-curricular interventions (ES = 0.30 [95% CI = -4.73, 5.34]) but no significant difference between the two models was found (z = 0.616, p = 0.538). The effect of change in CRF upon AP outcomes was trivial (β = -0.04 [95% CI = -1.52, 1.45]) with very poor precision ranging from negative to positive large effects (Figure 4.16).

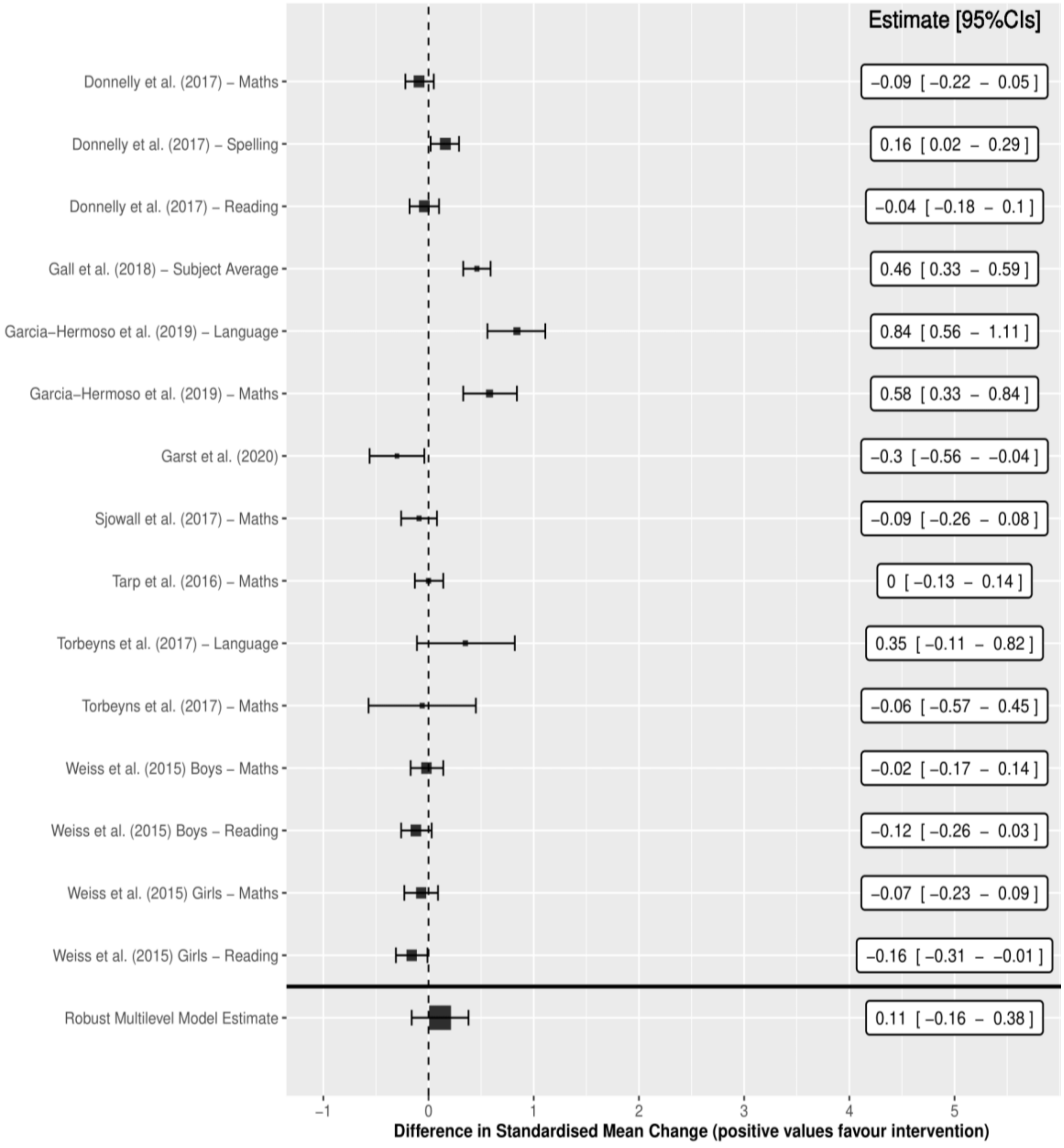

Figure 4. 13 Forest plot of academic performance outcomes

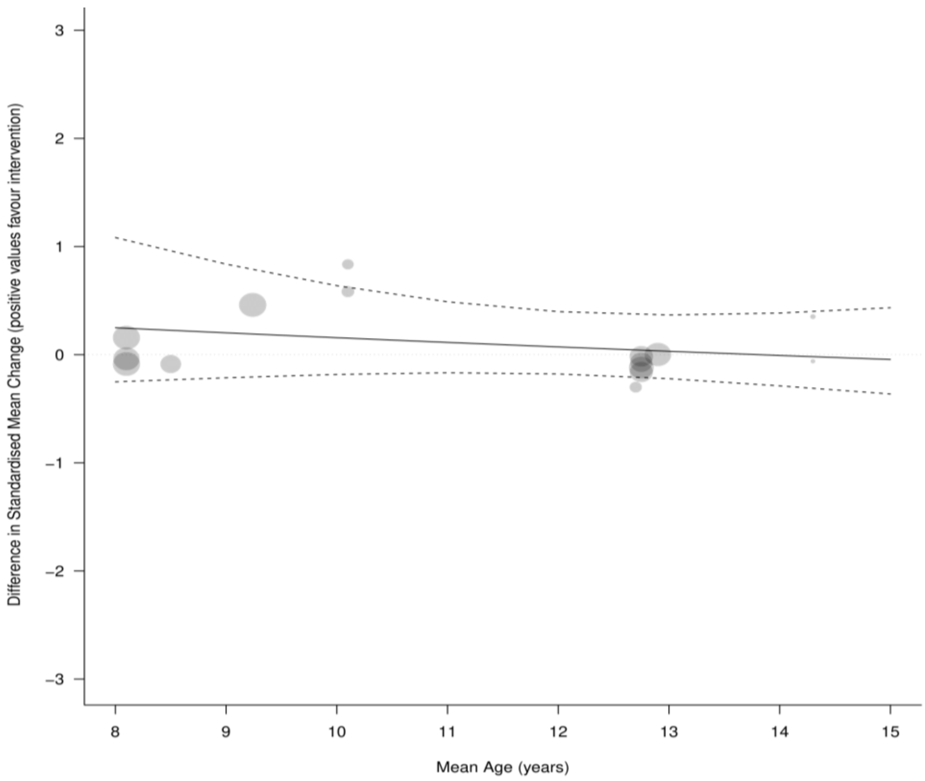

Figure 4. 14 Meta-analytic scatterplot of academic performance and age

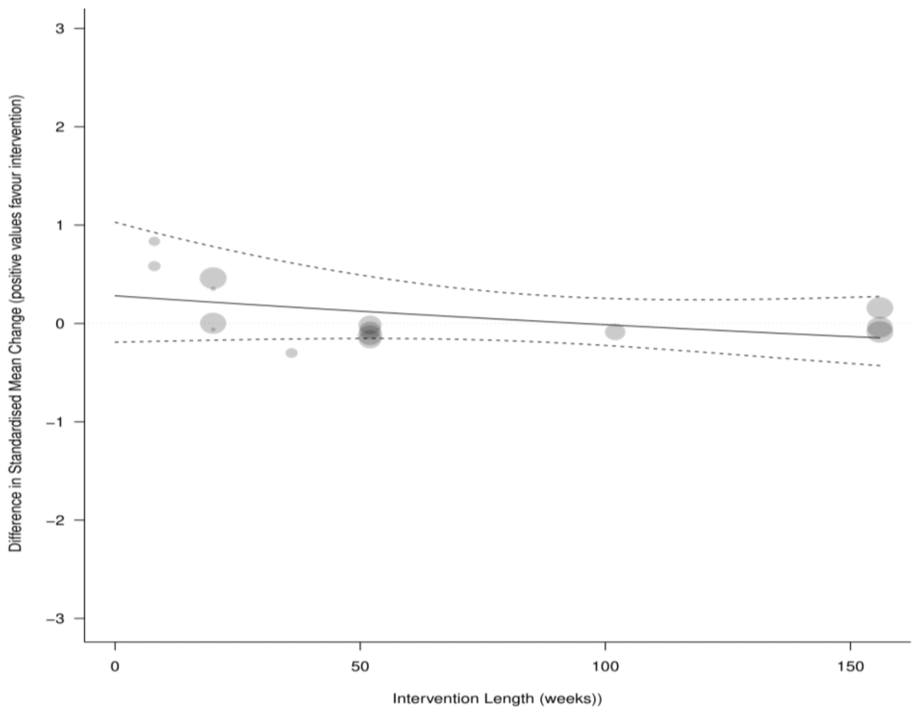

Figure 4. 15 Meta-analytic scatterplot of academic performance and intervention length

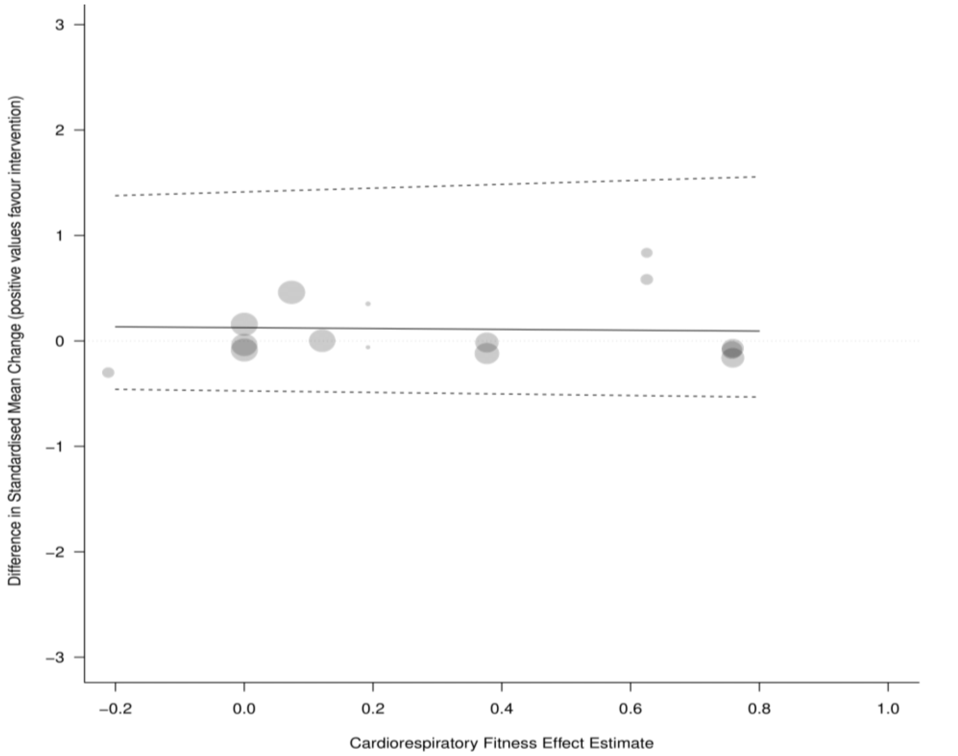

Figure 4. 16 Meta-analytic scatterplot of academic performance and cardiorespiratory fitness

4.4 Discussion

To the best of the thesis author's knowledge, this is the first systematic review, meta-analysis and meta-regression that has investigated both the impact of PA interventions upon CRF, executive function and academic performance, in addition to the association of changes in CRF with changes in executive function or academic performance resulting from PA interventions in children and adolescents. Overall, results from the meta-analysis suggest that PA interventions result in significant improvements in CRF but the results were less clear for executive function and academic performance. Further, though the moderating effect of CRF outcomes upon executive function outcomes was initially estimated to be moderate the precision of this estimate was poor and removal of a highly influential study (van der Niet et al., 2016) reduced this to a small imprecise effect. The moderating effect of CRF outcomes on academic performance outcomes was also trivial and highly imprecise. Thus, although PA interventions might positively impact upon CRF outcomes, these are unlikely to moderate the impact upon executive function and academic performance outcomes both of which seem trivial and unclear.

4.4.1 Physical Activity, Cardiorespiratory Fitness and Executive Function

The current meta-analysis found that while participating in a PA intervention resulted in a small improvement in CRF in line with the findings of Pozuelo-Carrascosa et al. (2018); yet, PA interventions seemed to have a trivial yet unclear effect upon executive function. This is in contrast to the evidence in the systematic review by Donnelly et al. (2016) who found that cross-sectional studies with designs accounting for confounding variables showed children with CRF performed consistently better in executive function tests. However, the result of the current study agrees with the meta-analysis performed by Verburgh et al. (2014), who found no meaningful effect of chronic physical exercise on executive function (ES = 0.16 [95% CI = -0.07, 0.39]). Verburgh et al. (2014) and the meta-analysis conducted in the present study disagree with the results of meta-analyses by Álvarez-Bueno et al. (2017a) (ES = 0.20 [95% CI = 0.10, 0.30]) and de Greeff et al. (2018) (ES = 0.24 [95% CI = 0.09, 0.39]) on the positive effects of a PA intervention on executive function in children and adolescents; though the results from these latter two meta-analyses suggest that at best there may only be small effects. However, considering the effect and interval estimates of the present analysis (ES = 0.15 [95% CI = -0.12, 0.41]) the upper interval estimate contains the reported effects from other meta-analyses. Though, in the present study, van der Niet et al. (2016) was removed and analyses re-conducted after influence and small study bias analysis which reduced the effect estimates in all models for executive function (main model, ES = 0.02 [95% CI = -0.09, 0.13]).

However, although this study was not yet published when Verburgh et al. (2014) conducted their meta-analysis and as such was not included, the meta-analyses performed by de Greeff et al. (2018) and Álvarez-Bueno et al. (2017a) did not remove this influential study. At present it seems unclear the extent to which PA interventions impact upon executive function which could range from trivial negative effects to small positive effects. Yet, while the magnitude of improvements in CRF resultant from PA interventions may exert a small moderating effect on executive function outcomes (β = 0.26 [95% CI = -0.18, 0.70]), this too is unclear.

4.4.2 Physical Activity, Cardiorespiratory Fitness and Academic Performance

The current study expands on previous systematic reviews that have investigated the relationship between CRF and academic performance. The systematic reviews conducted by Santana et al. (2017) and Donnelly et al. (2016) both found strong evidence of a link between CRF and academic performance in cross-sectional studies, whilst in longitudinal studies Santana et al. (2017) found an uncertain association (4 of 7 studies) and Donnelly et al. (2016) found a positive association (3 of 3 studies). However, there were no intervention studies included in either of these reviews, and due to many of the studies having relatively small sample sizes or using methodologies that were correlational it was not possible for the authors to determine a causal relationship. The current study adds to these reviews by analysing the findings of recently conducted intervention studies that investigated whether, when there is a change in CRF as a result of a PA intervention, there was also a change in academic performance, and the strength of this association.

The current meta-analysis of the eight intervention studies demonstrated that despite a small effect of PA intervention upon CRF, there was a trivial yet unclear effect upon academic performance. This result disagrees with two other meta-analyses conducted by Álvarez-Bueno et al. (2017b) (ES = 0.26 [95% CI = 0.07, 0.45]) and de Greeff et al. (2018) (ES = 0.26 [95% CI = 0.02, 0.49]). Álvarez-Bueno et al. (2017b) and Greef et al. (2018) investigated the effect of PA on academic performance, but did not measure CRF, and found significant small positive effects of PA on academic performance. Again though, considering the effect and interval estimates of the present analysis (ES = 0.11 [95% CI = -0.16, 0.38]) the upper interval estimate contains the reported effects from the other meta-analyses. This difference in effect size may be explained by the different studies analysed because of the inclusion criteria set by the authors not requiring a measurement of CRF, with only one common study shared in the current meta-analysis with Álvarez-Bueno et al. (2017b), and no studies shared with de Greeff et al. (2018). The studies included in the present analysis were those that included CRF as an outcome measure. Twelve of the seventeen studies included reported CRF as a primary outcome and were investigating how a PA intervention impacts CRF as well as academic performance/executive function. Thus, it might be expected that the interventions were designed with improving CRF in mind (i.e. being of sufficient intensity of effort, volume, and frequency). Santos et al. (2018) suggested that vigorous PA has a stronger prospective association with changes in CRF. However, only one study out of the eight that investigated changes in academic performance used vigorous PA (Sjöwall, Hertz & Klingberg, 2017), one study used activities that were moderate to vigorous intensity (Garcia-Hermosa et al., 2020), one study used light PA (Donnelly et al., 2017) and five studies did not specify the intensity of the PA in their interventions (Weiss, Phillips & Kipp, 2015; Gall et al., 2018; Tarp et al., 2016; Torbeyns et al., 2017; Garst et al., 2020).

Future studies should specify the intensity of PA used in their interventions to determine the effects of different PA intensities on academic performance and executive function.

The meta-regression performed in this study found that there was little evidence to suggest a moderating effect of CRF changes upon academic performance outcomes (β = -0.04 [95% CI = -1.52, 1.45]). This is supported by the findings of Lubans et al. (2018), who found that there was no significant association between changes in MVPA and mathematic performance, even though they had found a significant positive effect on mathematic performance from their PA intervention. The lack of a positive effect upon academic performance found in the eight intervention studies is a finding worth further consideration. Seven of the eight studies increased the PA of children during curricular activities through active academic lessons or enhanced/additional PE lessons. This demonstrates that the additional PA had no negative effect on their performance academically and had a positive impact on their CRF. With the future health benefits of improving CRF being well documented (Mintjens et al., 2018), it can be recommended that dedicating more time during the school day to increasing PA is beneficial, as it improves CRF and does not impair children's academic performance.

4.4.3 Previously Proposed Mechanisms Linking Physical Activity, Cardiorespiratory Fitness, Executive Function and Academic Performance

There are several underlying mechanisms that have been previously proposed to explain the links between PA, CRF, executive function and academic performance. Firstly, students who achieve better academically may be more orientated for success, and therefore more likely to achieve success academically and in fitness (Thørgersen-Ntoumani & Ntoumanis, 2006). This may be an explanation as to why there are stronger associations in cross-sectional studies. Secondly, a longitudinal PA intervention that increases children's CRF can enhance angiogenesis and neurogenesis in the areas of the brain, that are used for memory and learning, which in turn can improve executive function and academic performance (Hillman et al., 2009; Isaacs et al., 1992). Thirdly, cognitively engaging PA is hypothesised to have more of a benefit on executive function and academic performance than repetitive aerobic exercise, such as long-distance running (Vazou et al., 2016). Due to the limited number of studies, sub-group analysis by PA type was not performed. However, Schmidt et al. (2015) investigated the effects of the different types of PA on executive function and found that both the "Team Games" and "Aerobic Exercise" groups improved their CRF significantly in comparison to the control group but only the "Team Games" group increased their executive function significantly. These findings are also supported by the meta-analysis conducted by de Greeff et al. (2018) who found a greater effect size for cognitively engaging PA interventions (ES = 0.53 [95% CI = 0.14, 0.92]) in comparison to aerobic PA (ES = 0.29 [95% CI = 0.13, 0.45]). However, despite these plausible mechanisms for the role of PA in improving executive function and academic performance, potentially through its effects upon CRF, the results of the present study do not support this. The analysis was limited to findings from studies that examined both CRF outcomes and executive function and/or academic performance outcomes and suggests that, at best, PA interventions may produce small improvements in CRF whilst having, at worst, trivial negative impact upon executive function or academic performance. Thus, CRF seems unlikely to mediate any link between PA and executive function or academic performance. Yet, PA interventions do not negatively impact executive function or academic performance is an important finding as it dispels the often held myth that PA interventions could distract students from pursuits related to the improvement of academic performance (Coe et al., 2006; Tsai et al., 2009; Arnold et al., 2016). The present study suggests that PA interventions, even those conducted during curricular time, may improve CRF whilst likely avoiding negative impact upon academic performance. With the future health benefits of improving CRF being well documented (Mintjens et al., 2018), the possible value of dedicating time during the school day to increasing PA and thus CRF should be considered given its negligible negative impact upon children's academic performance.

4.4.4 Strengths and Limitations

This is the first systematic review and meta-analysis of studies examining the impact of PA interventions upon CRF, executive function and academic performance, in addition to the association of changes in CRF with changes in executive function and academic performance resulting from PA interventions. One of the major strengths of this chapter was that only intervention studies were included, which enabled conclusions to be drawn on the effects of PA interventions on CRF, executive function and academic performance. Another key strength of this chapter was the use of the PRISMA statement to guide the structured electronic literature search. Furthermore, stringent inclusion criteria were used in the electronic literature search. For example, by only including children and adolescents aged 5-18 years at baseline the results were not obscured by adult participants.

There are several limitations of the current meta-analysis that need to be considered. Firstly, some studies were not included in the meta-analysis due to the way the results had been reported in the published article. For example, Reed et al. (2013) reported means but not standard deviations so effect sizes could not be calculated. All authors were contacted to obtain any unpublished data that was required, some did not reply, and others said they were unable to provide the data requested as the data were not available. Secondly, the thesis author did not search for unpublished studies or include grey literature, which could allow publication bias to influence the results as studies that reported no association may not have been published. Thirdly, measurements of CRF, executive function, and academic performance were standardised by calculating effect sizes, however the validity and reliability of the individual measures varies. Fourthly, although some moderators were investigated (age and length of intervention) there are different types of moderators that influence the physiological response to PA that were not included in the current meta-analysis. One example of this is the intensity of effort of the PA undertaken by the participants in the intervention. This was not included due to most of the studies not using a method to standardise or measure this. It is therefore recommended that future studies monitor the intensity of effort of the PA used in the interventions. Fifthly, as the intention of the analysis was to examine the moderating effects of CRF changes upon executive function and/or academic performance changes, the inclusion criteria was limited to studies measuring both outcomes. As such, the estimates reported from the main models (i.e. without moderation for CRF) should be treated cautiously as they do not include all studies that have examined these outcomes independently. Finally, due to the fact that it is uncommon for correlation matrices or raw data to be available from intervention studies limiting the ability to conduct mediation analysis, the moderation analyses conducted were limited to the association of changes in CRF with changes in executive function or academic performance at the study/group level. This means that the moderation results reflect only the extent to which CRF changes as associated with PA interventions effects upon executive function or academic performance changes.

4.5 Conclusions

Previously, PA and CRF have been associated with executive function and academic performance (Donnelly et al., 2016; Santana et al., 2017), and doing more PA has been shown to improve executive function and academic performance (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b). Researchers have speculated that improvements in CRF mediate the impact of PA on executive function and academic performance (North, McCullagh & Tran, 1990). However, this assumes that PA interventions improve CRF, and that the PA intervention induced improvement in CRF is associated with any resultant improvement in executive function and academic performance. Therefore, in order to examine this, studies need to include measures of CRF to determine whether the PA intervention actually improved CRF and to enable the examination of the relationships between the changes in CRF and changes in executive function and academic performance.

In conclusion, this meta-analysis has found that, while PA interventions may produce small improvements in CRF in children and adolescents, PA intervention impact upon executive function or academic performance is less clear. Further, it seems unlikely that the improvements in CRF produced by PA interventions are associated with changes in executive function or academic performance. This is particularly noteworthy given that most of the PA interventions took place during time normally allotted for curricular activities. This suggests that schools can implement PA into the curriculum with the aim of improving children's CRF, which is associated with numerous health benefits for children in their present and future, and that concern regarding the negative impact of such interventions may be unfounded.

Key Findings in Relation to Thesis

Study 1:

- The literature search performed in Study 1 highlighted that numerous studies do not measure CRF post-intervention. As highlighted in the literature review, CRF is an important health outcome that modifying PA behaviour aims to improve and should therefore be a routine measure post-intervention.
- The inclusion of measurements of CRF in studies of PA interventions in children is key to the evaluation of their impact. This study has demonstrated that inclusion of such outcomes facilitates the quantitative synthesis of effects to best understand the impact of PA interventions.
- Further, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that have utilised CRF testing as an outcome, the current study was able to examine this hypothesis.
- The lack of association between improvements in CRF with changes in executive function and academic performance therefore warrant no further research in this thesis.

CHAPTER 5.0 STUDY 2: THE IMPLEMENTATION OF CARDIORESPIRATORY FITNESS TESTING OF CHILDREN FOR NATIONAL AND INTERNATIONAL COHORT COMPARISONS

5.1 Introduction

Cardiorespiratory fitness (CRF) is a strong summative marker of children's physical health (Oretga et al., 2008b), and has been found to be meaningfully associated with physical health, independent of physical activity (PA) levels in children and youth (Ekelund et al., 2007; Steele et al., 2008). Further, despite Study 1 (Thesis Chapter 4.0) showing that improvements in CRF had no significant effect on executive function or academic performance, higher CRF levels have been found to be associated with better executive function (Donnelly et al., 2016), academic performance (Santana et al., 2017) and mental health (Kandola et al., 2019).

Despite the well-documented benefits of high levels of CRF, there has been a substantial decline in CRF for several decades globally (Tomkinson et al., 2019b). This public health problem is of particular concern in England, with data indicating that CRF is decreasing by 5.2% per decade compared to the international average of -0.9% per decade (Tomkinson et al., 2019b). Lang et al. (2018a) highlighted how CRF surveillance would allow for comparisons within a country. This sort of data could be used to monitor children's health status in different regions and population groups, which could help scientific researchers, local authorities, and governing bodies implement more effective policies and interventions to improve the health of children. However, in England the issue has been complicated further by the lack of contemporary datasets from the different English regions. There are only a few datasets available for English children including the SportsLinx project (Boddy et al., 2012a) in the North West of England, the Chelmsford Children's Fitness and Activity Survey (CCFAS; Sandercock, Ogunleye & Voss, 2015) and the East of England Healthy Hearts Study (EEHHS; Voss & Sandercock, 2011) in the East of England, and the SOFit study (Weston, Pasecinic & Basterfield, 2019) in the North East of England. To date, there are no published data on the CRF of children from London who have the second highest obesity levels in the country (23.7%). Further, there are inconsistencies between the published datasets in regards to the participants (e.g. age and socioeconomic status (SES)). The datasets from CCFAS and EEHHS projects involved children from rural and urban areas where levels of deprivation were lower (Cohen et al., 2011; Voss & Sandercock, 2011), whereas the children from SportsLinx and SOfit projects were more representative of urban areas with higher levels of deprivation (Ministry of Housing, Communities & Local Government, 2019).

Recently, youth-specific international normative values for CRF have been developed (Tomkinson et al., 2017). In addition to aiding the surveillance and monitoring within a country, Lang et al. (2018a) highlighted how these normative values could be used to compare levels between countries. Due to Premier Education expanding their business to the US, a convenience sample was available for analysis. Previously, comparisons in CRF between the UK and US could be made through studies such as those conducted by Lang et al. (2018b), where data on numerous countries was pooled and ranked. The US was ranked 47th of 50 countries (UK ranked 21st) by performance index in CRF by Lang et al. (2018b). There has also been a decrease in CRF in both countries since the turn of the century, with the decrease in the UK (-5.2% per decade) double that of the US (-2.6% per decade; Tomkinson et al., 2019b). However, there have not been any studies that have directly investigated the CRF levels of children between England and the US alone.

The overarching aim of this study was to provide examples of how CRF testing on a national scale could be utilised by conducting cohort comparisons. This study aimed to achieve this by:

1) Assessing and comparing the CRF of children from London with studies that have measured CRF of children in different regions in England.
2) To provide a cross-country comparison between the CRF levels of children in England with a convenience sample of children in the US and demonstrate the feasibility of implementing testing procedures in different countries.

5.2 Methods

5.2.1 Participants and Settings

Two cohorts of children participated in the study, My Personal Best Challenge (MPBC) London and MPBC US. MPBC London were children (*n* = 1,901) from 17 primary schools in the London boroughs of Camden and Islington in England. MPBC US were children (*n* = 782) from 9 elementary schools in Birmingham, Alabama and Oakland, California in the US. Participants in both cohorts were recruited through their school's involvement in programmes being administered by Premier Education. Children in MPBC London were in academic Years 4 to 6, aged 8-11 years old. Children in MPBC US were in grades 4 and 5, aged 9-11 years old. The children in MPBC London were the same participants that were recruited for subsequent studies 3 and 4 (Thesis Chapters 6.0 and 7.0).

5.2.2 Ethics

Approval was received from Coventry University's ethical committee (P60795 & P68526). Informed consent and information sheets were sent out to headteachers/principals and parents/guardians. Data from the children was only used if they had returned signed informed consent. Headteachers/principals, parents/guardians and children were informed that they could withdraw from the study at any point.

5.2.3 Instruments and Procedures

In the present study, testing was administered by Premier Education staff in England and the US. Premier Education is a children's coaching company who provide PA sessions in over 3,000 schools throughout the UK and deliver 25,000 PA sessions each month. Premier Education had recently expanded their company and services to the US.

5.2.3.1 Cardiorespiratory Fitness

Children completed the 20mMSR as part of the MPBC, which has been described previously in Thesis Chapter 3.0 (Pages 68-70). The global reference values were used to calculate age- and sex-specific z-scores (Tomkinson et al., 2017), and the end speed was used to calculate peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) ($ml \cdot kg^{-1} \cdot min^{-1}$). $\dot{V}O_{2peak}$ was calculated using the Léger et al.'s (1984) prediction equation (Table 2.1, Page 17).

5.2.4 Statistical Analysis

The number of shuttles, end speed, $\dot{V}O_{2peak}$ and age- and sex-specific fitness z-scores were reported as CRF measurements. Following the recommendations by Tomkinson et al. (2017) a quintile framework was adopted for reporting purposes. Participants in centiles < 20th were categorised as having "very low", between 20th and 40th percentiles were "low", between 40th and 60th percentiles were "moderate", between 60th and 80th percentiles were "high" and between > 80th percentile were "very high" levels of CRF. For the exact scores corresponding to the centile please see Tomkinson et al. (2017).

To assess if there were any significant differences between the current study's English dataset (MPBC London) and other published studies in England, summary data (sample size, mean and SD) was used (if available) in 2 samples t-tests or one-way analysis of variance (ANOVA), with a significance level of $p < 0.05$. All authors were contacted if means and standard deviations were not available for 20mMSR shuttles. A narrative review was completed if data to permit calculation of the one-way ANOVAs or t-tests was not available. For individual studies that had used a repeated cross-sectional design, the most recent CRF scores were used. For projects where multiple studies have been published with updates of CRF levels, the most recent study was referenced.

Differences between boys and girls in MPBC London and MPBC US were analysed by independent t-tests. Analysis of covariance (ANCOVA) values were used to analyse potential differences in CRF between the current study's English and US datasets. The "CRF measurements" (no. of shuttles, end speed, $\dot{V}O_{2peak}$ and z-scores) were each used as the dependent variable. The independent variable was "Cohort", and "sex" and "age" were entered as covariates.

5.3 Results

5.3.1 Comparison of MPBC London with other English regions

Studies reported CRF using different methods as shown in Table 5.1. The datasets reported in Table 5.1 can be found in the following publications; Boddy et al. (2012a), Sandercock, Ogunleye and Voss (2015), Sandercock et al. (2012) and Weston, Pasecinic and Basterfield (2019).

As publicly available raw data on CRF is limited from English datasets, one-way ANOVAs and independent t-tests using summary measures (sample numbers, means and standard deviations) were used to compare the findings from the different datasets. The differences in CRF are shown in Table 5.2. The 20mMSR performance of boys in the MPBC London cohort was significantly lower than the boys in the SportsLinx project from the North West (mean difference = -5.9 shuttles [95% confidence intervals (CI) = -8.2 to 3.5], $p < 0.001$) and boys from the East of England in the EEHHS project (mean difference = -5.8 shuttles [95% CI = -9.3 to 2.3], $p < 0.001$). Girls from the East of England in the EEHHS project also had significantly higher 20mMSR performance than the girls in the MPBC London cohort (mean difference = -4.4 shuttles [95% CI = -7.1 to -1.7], $p < 0.001$). However, the relative $\dot{V}O_{2peak}$ of the MPBC London cohort was significantly higher than the EEHHS cohort for boys (mean difference = 1.2 $ml \cdot kg^{-1} \cdot min^{-1}$, t (df = 1043) = 3.63, $p < 0.001$) and girls (mean difference = 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$, t (df = 1041) = 5.315, $p < 0.001$). There were no significant differences between 20mMSR performance between the MPBC London cohort and the SOFit project in the North East of England for boys ($p = 0.930$) or girls ($p = 0.997$). The mean number of shuttles was not obtained from the CCFAS project from the East of England. Visual comparison of the medians between the children in the CCFAS project and the children from the MPBC London cohort showed that boys and girls in the CCFAS project had higher 20mMSR performance. However, when z-scores were compared the MPBC London cohort had significantly higher CRF compared to the CCFAS cohort for boys (mean difference = 0.80, t (df = 901) = 9.22, $p < 0.001$) and girls (mean difference = 0.43, t (df = 898) = 5.44, $p < 0.001$). When comparing the end speed in the 20mMSR, the MPBC London cohort had a significantly higher end speed compared to the boys in the CCFAS cohort (mean difference = 0.4 $km \cdot h^{-1}$, t (df = 901) = 4.141, $p < 0.001$).

Table 5. 1 Descriptive statistics of CRF between MPBC London cohort and studies from other regions in England

	MPBC London (London, 2016-2018)			SportsLinx[1] (North West, 2009-2010)		CCFAS[2] (East, 2014)		EEHHS[3] (East, 2006-2010)		SOFit[4] (North East, 2019)		
	Boys (*n* = 746)	Girls (*n* = 750)	All (*n* = 1496)	Boys (*n* = 1073)	Girls (*n* = 1086)	Boys (*n* = 157)	Girls (*n* = 150)	Boys (*n* = 299)	Girls (*n* = 293)	Boys (*n* = 32)	Girls (*n* = 43)	All (*n* = 75)
Age[a] (years)	9.6 (0.8)	9.5 (0.9)	9.5 (0.9)	9.8 (0.4)	9.8 (0.4)	10.8 (0.4)	10.8 (0.4)	10	10	9.3 (0.6)	9.0 (0.5)	9.1 (0.6)
20mMSR[a] (shuttles)	34.8 (20.6)	27.5 (17.3)	31.1 (19.3)	40.7 (19.6)	28.3 (13.5)			40.6 (21.7)	31.9 (15.8)	37 (11)	27 (10)	31 (11)
20mMSR[b] (shuttles)	31 [33]	22 [24]	25 [28]			33 [31]	27 [14]			36 [16]	24 [16]	30 [16]
End speed[a] ($km \cdot h^{-1}$)	10.3 (1.1)	9.8 (1.0)	10.1 (1.1)			9.9 (1.1)	9.8 (0.8)	10.2 (1.2)	9.7 (1.0)			
Relative $\dot{V}O_{2peak}$[a] ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.3 (5.3)	46.4 (4.7)	47.4 (5.1)					47.1 (5.6)	44.7 (4.6)			
20mMSR[a] (z-score)	0.18 (1.25)	0.15 (1.32)	0.17 (1.28)			-0.64 (0.92)	-0.28 (0.78)			-0.10	-0.10	

[1]*SportsLinx (Boddy et al. 2012a),* [2]*CCFAS (Sandercock, Ogunleye & Voss, 2015),* [3]*EEHHS (Sandercock et al. 2012),* [4]*SOFit (Weston, Pasecinic and Basterfield 2019)*

[a]*Mean (SD),* [b]*Median [IQR]*

Table 5. 2 Mean differences [95% CI] in CRF between English studies

A	B	Mean Difference (A-B) [95% CI]							
		20mMSR (shuttles)		End Speed ($km \cdot h^{-1}$)		Relative $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)		20mMSR z-scores	
		Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
MPBC London	SportsLinx[1]	-5.9‡ [-8.3 to 3.5]	-0.8 [-2.6 to 1.0]						
MPBC London	CCFAS[2]			0.4‡ [0.17 to 0.63]	0 [-0.21 to 0.21]			0.82‡ [0.61 to 1.02]	0.43‡ [0.22 to 0.65]
MPBC London	EEHHS[3]	-5.8‡ [-9.3 to -2.3]	-4.4‡ [-7.1 to -1.7]	0.1 [-0.08 to 0.28]	0.1 [-0.06 to 0.26]	1.2† [0.48 to 1.92]	1.7‡ [1.07 to 2.33]		
MPBC London	SOFit[4]	-2.2 [-11.5 to -7.1]	0.5 [-5.5 to 6.6]						
SportsLinx[1]	EEHHS[3]	0.1 [-3.2 to 3.4]	-3.6† [-6.1 to -1.1]						
SportsLinx[1]	SOFit[4]	3.7 [-5.6 to 13.0]	1.3 [-4.7 to 7.3]						
CCFAS[2]	EEHHS[3]			-0.3* [-0.56 to -0.04]	0.1 [-0.13 to 0.33]				
EEHHS[3]	SOFit[4]	3.6 [6.0 to 13.2]	4.9 [-1.4 to 11.2]						

[1]SportsLinx (Boddy et al. 2012a), [2]CCFAS (Sandercock, Ogunleye & Voss, 2015), [3]EEHHS (Sandercock et al. 2012), [4]SOFit (Weston, Pasecinic and Basterfield, 2019)

**p < 0.05, †p < 0.01, ‡p < 0.001*

5.3.2 Comparison of CRF between MPBC London and MPBC US cohorts

Participants' descriptive data and the number of participants assessed are shown in Table 5.3. The mean percentage for the eligibility of children entitled to free school lunches were 23.8% and 60.0% for MPBC London and MPBC US cohorts, respectively. In both MPBC London and MPBC US cohorts, eligibility for free school meals was normally dependent on household income (UK Government n.d.; US Department of Agriculture, 2019). However, the eligibility criteria also depends on the number of people in the household as well as location. In the MPBC London cohort, 477 children were aged 10 years or older, and the percentage of boys and girls in the Healthy Fitness Zone was 86.6% and 70.5%, respectively. In MPBC US cohort, 462 children were aged 10 years or older, and the percentage of boys and girls in the Healthy Fitness Zone was 57.9% and 37.1%, respectively.When the two cohorts were compared to the international reference data using the z-scores from Tomkinson et al. (2017), there was no meaningful difference between the CRF scores for children from England but a much larger difference for the children from the US (Table 5.3).

Table 5. 3 Descriptive statistics for the CRF of MPBC London and MPBC US cohorts

	MPBC London, mean (SD)			MPBC US, mean (SD)		
	Boys (*n* = 746)	Girls (*n* = 750)	All (*n* = 1496)	Boys (*n* = 400)	Girls (*n* = 382)	All (*n* = 782)
Free school meal eligibility (%)	22.4 (14.9)	25.2 (9.1)	23.8 (12.5)	67.8 (24.9)	51.8 (24.2)	60.0 (25.8)
Age (years)	9.6 (0.8)	9.5 (0.9)	9.5 (0.9)	9.58 0.49	9.58 0.49	9.58 (0.49)
20mMSR (shuttles)	35 (21)	28 (17)	31 (19)	25 (16)	18 (11)	21 (14)
20mMSR end speed ($km \cdot h^{-1}$)	10.26 (1.13)	9.85 (0.96)	10.05 (1.07)	9.70 (0.68)	9.31 (0.68)	9.51 (0.83)
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.3 (5.3)	46.4 (4.7)	47.4 (5.1)	44.7 (4.5)	42.7 (3.4)	43.7 (4.1)
20mMSR (z-score)	0.18 (1.25)	0.15 (1.31)	0.15 (1.28)	-0.48 (0.98)	-0.57 (0.87)	-0.52 (0.93)

Independent t-tests found that there was a significant difference between boys and girls in the 20mMSR (shuttles), end speed and relative VO_{2peak} for both the MPBC London ($p < 0.001$) and MPBC US ($p < 0.001$) cohorts (Table 5.4). However, there were no significant differences between boys and girls for the 20mMSR z-scores in either MPBC London ($p = 0.731$) or MPBC US ($p = 0.164$). Children in MPBC London had significantly better CRF than MPBC US ($p < 0.001$) after adjusting for age and sex (Table 5.4). In the 20mMSR, MPBC London children ran significantly further compared to children in MPBC US ($F = 189.26$, p < 0.001). The end speed was also significantly higher for children in MPBC London compared to MPBC US ($F = 183.81$, $p < 0.001$). Children in MPBC London also had significantly higher VO_{2peak} compared to children in MPBC US ($F = 189.88$, $p < 0.001$). There was also a significant difference between 20mMSR z-scores, with MPBC London children having a significantly higher z-score than children in MPBC US ($F = 169.61$, $p < 0.001$). Similar significant differences were found when stratified by sex (Table 5.4).

Table 5. 4 Mean differences [95% CI] between boys and girls and between MPBC London and MPBC US cohorts

CRF Measurement	Mean Differences (Boys – Girls) [95% CI][a]		Mean Differences (MPBC London – MPBC US) [95% CI][b]		
	MPBC London	MPBC US	Boys	Girls	All
20mMSR (shuttles)	7.3‡ [5.4 to 9.2]	6.9‡ [4.9 to 8.9]	12.1‡ [9.7 to 14.6]	10.3‡ [8.2 to 12.3]	11.3‡ [9.7 to 12.9]
End speed ($km \cdot h^{-1}$)	0.41‡ [0.30 to 0.52]	0.39‡ [0.27 to 0.50]	0.66‡ [0.53 to 0.80]	0.56‡ [0.45 to 0.68]	0.62‡ [0.53 to 0.71]
Relative $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	1.83‡ [1.32 to 2.34]	1.93‡ [1.37 to 2.49]	3.22‡ [2.58 to 3.86]	2.72‡ [2.16 to 3.27]	2.98‡ [2.56 to 3.41]
20mMSR (z-score)	0.02 [-0.11 to 0.15]	0.09 [-0.04 to 0.22]	0.71‡ [0.56 to 0.86]	0.73‡ [0.57 to 0.89]	0.72‡ [0.61 to 0.83]

**p* < 0.05, †*p* < 0.01, ‡*p* < 0.001*

[a]*Independent t-test,* [b]*One-way ANCOVA (adjusting for sex and age)*

The CRF for children in the MPBC London and MPBC US cohorts are reported in quintiles corresponding to "very low", "low", "moderate", "high", and "very high" (Figure 5.1). There were significant Chi-Square tests of independence between the MPBC London and MPBC US for boys (χ^2 (df = 4) = 66.65, $p < 0.001$), girls (χ^2 (df = 4) = 95.94, $p < 0.001$) and all children (χ^2 (df = 4) = 158.18, $p < 0.001$). Post-hoc analysis showed that the proportion of children (boys, girls and all children) that were categorised as having a "very low" level of CRF was significantly smaller ($p < 0.05$) in MPBC London compared to MPBC US. The proportion of children (boys, girls and all children) categorised as having a "very high" level of CRF was significantly higher in MPBC London compared to MPBC US. There was a significantly higher ($p < 0.05$) proportion of children (boys, girls and all children) in MPBC London that were categorised as "High" compared to MPBC US, and a significantly higher ($p < 0.05$) proportion of MPBC London girls in the "Moderate" quintile compared to the MPBC US girls.

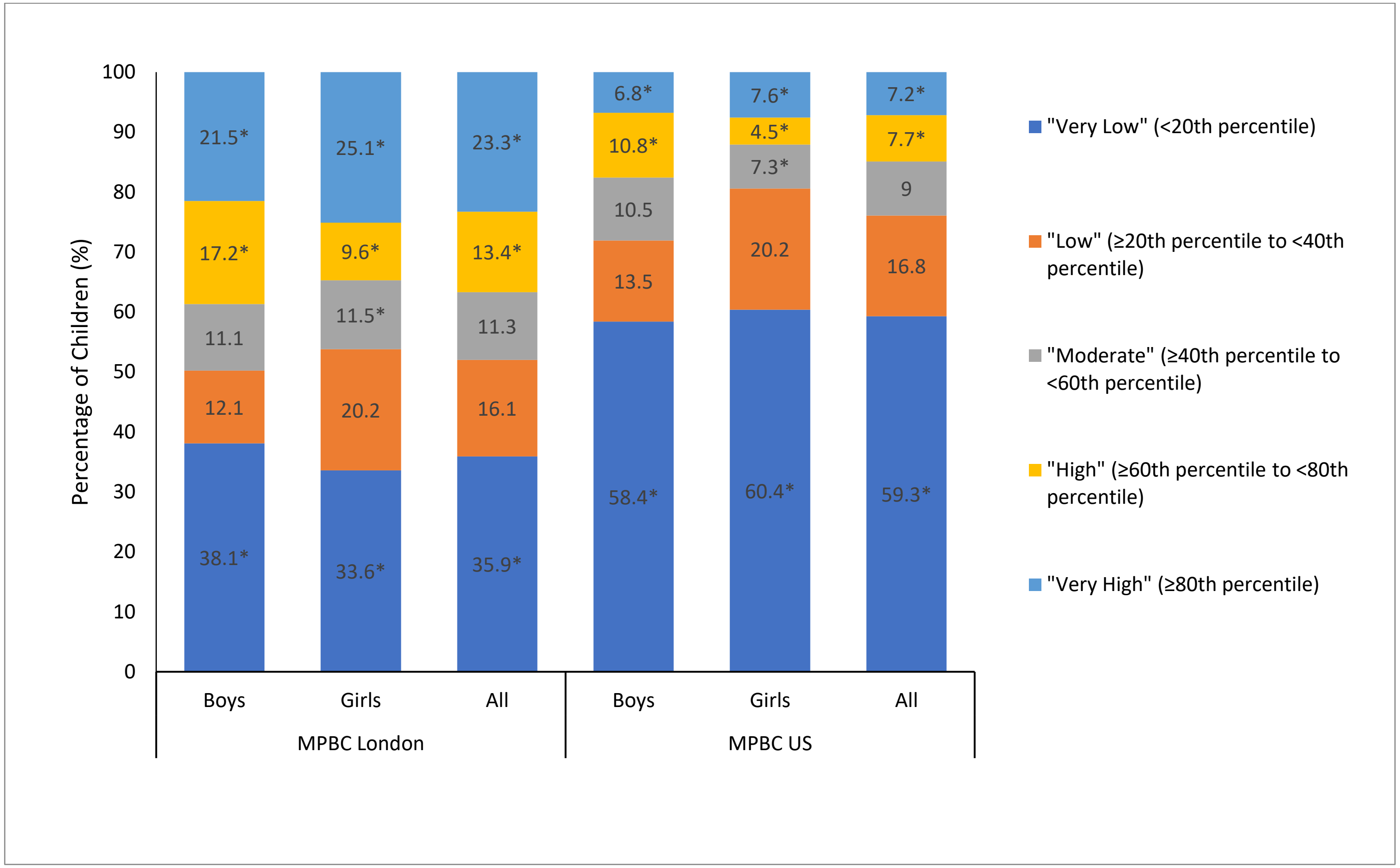

Figure 5. 1 Quintile classification framework for CRF of children in different CRF categories, for children from England (MPBC London) and the US (MPBC US), based on international normative values as reported by Tomkinson et al. (2017).

*Significant difference ($p < 0.05$) between MPBC London and MPBC US in CRF quintile.

5.4 Discussion

The overarching aim of this chapter was to provide an example of how measurement of CRF in children can be utilised in cohort comparisons. This chapter aimed to achieve this by:

1) Comparing CRF of children from London with previous studies in different regions of England.
2) A cross-country comparison of children's CRF levels between children who completed the MPBC in England with children from the US.

5.4.1 MPBC London comparison with other English studies

The first objective of this chapter was to compare the CRF levels of children from 17 primary schools in London with other contemporary youth studies in England. This allowed for a more comprehensive understanding into children's CRF levels from the different regions across England. This would enable the government, as well as local authorities, to identify which regions need additional support or whether CRF levels are stable across England and examine what practices regions that have higher CRF already have in place. This may help identify possible interventions that could be addressed in future research or policy and evaluation.

The comparison of the MPBC London data with the z-scores derived from international age- and sex-related data (Tomkinson et al., 2017) demonstrated that the children in the study were slightly above the average CRF levels for their peers globally (mean = 0.17, 95% CI = 0.10, 0.23). This finding agrees with the findings of Lang et al. (2018b) who accumulated data from over 50 countries and reported the UK having a percentile rank of 62 and a mean z-score of 0.31 (95% CI = 0.30, 0.32). The lower z-score found in the current study compared to the accumulated findings by Lang et al. (2018b) may be due to the populations used in their analysis, with several large-scale studies coming from Northern Ireland in the 1980s and 1990s (Mahoney, Boreham & Nichols, 1991; Riddoch et al., 1991; Twisk et al., 1999). Not only is Northern Ireland geographically discrete from the rest of the UK but these studies were prior to the increase in the prevalence of obesity seen across the UK in the 1990s and early 2000s (Health Survey for England, 2018).

The current study found that boys and girls from London had significantly lower CRF (when reported as the number of shuttles completed in the 20mMSR) than boys and girls from the East of England ($p < 0.001$) and boys from Liverpool ($p < 0.001$). Girls from the East of England also completed significantly more shuttles than girls from Liverpool ($p < 0.001$). There were no significant differences between children from London with children from the North East. The differences in CRF between regions may be explained by the varying prevalence of obesity in the different regions. Comparison of the data on the prevalence of childhood obesity for children in Year 6 (aged 10-11 years) from National Child Measurement Programme (NCMP) shows that the East of England has a lower proportion of children who are overweight or obese (32.7%) compared to the North West (37.4%), the Nort East (37.5%) and London (38.2%; Public Health England, 2021). These regional differences in the prevalence of childhood obesity are supported by the current study's findings with children from the MPBC London cohort having similar BMI z-scores to children from the North East in the SOFit study (Weston, Pasecinic and Basterfield, 2019), 0.51 and 0.51 respectively. Boys and girls in the MPBC London cohort also had higher BMI z-scores (boys = 0.62, girls = 0.39) than children in the CCFAS study in the East of England (boys = 0.14, girls = 0.27; Sandercock, Ogunleye & Voss, 2015).

The NCMP has reported how deprivation is associated with obesity, with Year 6 children from the most deprived areas twice as likely to be obese (26.9%) compared to children living in the least deprived areas (11.9%; NHS, 2019). This agrees with the findings of Nevill et al. (2018) who established that children from more deprived areas were less physically fit and were more likely to be obese. Interestingly, Nevill et al. (2018) reported that the association between obesity and deprivation disappeared when fitness was included within their logistic regression model, i.e. if all children had the same levels of CRF, the differences in deprivation would no longer be significant. However, the current study's findings show that children's CRF does vary in different geographical locations. The higher number of shuttles completed in the 20mMSR by children from the East of England compared to the other regions may be associated with the deprivation of the respective areas, with Sandercock et al. (2012) reporting that their sample from the East of England was less deprived than most of England according to the English Indices of Deprivation in 2007. When comparing the different local authorities that the samples were from and using the Indices of Multiple Deprivation (IMD), Chelmsford in the East of England, had a lower IMD rank (10,004.42) than London (12,420.52), Gateshead in the North East (20,831.18) and Liverpool in the North West (25,833.57; Ministry of Housing, Communities & Local Government, 2019).

There are methodological issues that need to be considered. The lack of raw data, and differences in the methods used to report the summary data made it difficult to draw conclusions on potential differences between all of the English cohorts. For example, the CCFAS project did not report the mean or SD for their data but only the median. All lead authors were contacted and summary data was requested, yet this was not provided by all authors. The protocols of the 20mMSR also varied between the different studies in

England or were not specified at all, which makes comparisons more problematic. For example, the SportsLinx project used the Queen's University of Belfast protocol for the 20mMSR (Riddoch, 1990), which starts at 8.0 km·h^{-1} and increases by 0.5 km·h^{-1}. The Léger et al. (Léger et al., 1984; Léger et al., 1988) protocol, which was used in the MPBC programme, begins at 8.5 km·h^{-1} and then increases by 0.5 km·h^{-1}. By only examining the mean number of shuttles completed for MPBC and SportsLinx cohorts it would be possible to assume that boys in the SportsLinx cohort had higher levels of CRF (41 shuttles compared to 35 shuttles). Further examination into the protocols shows that the end speed for the Queen's University of Belfast protocol at 41 shuttles is 10.0 km·h^{-1} and the Léger et al. protocol at 35 shuttles is also 10.0 km·h^{-1}. Therefore, children could have run different number of shuttles but could drop out with the same end speed depending on the 20mMSR protocol used.

In summary, this section highlights how CRF may vary in the different regions of England and how this may be associated with obesity and/or deprivation. This study also demonstrates that there are limited data sets available for children's CRF in English schoolchildren, with results restricted to certain regions of the country whilst non-existent in others. All the studies in England measured CRF levels using the 20mMSR, however the protocol of the 20mMSR varied between the studies. The Léger et al. (Léger et al., 1984; Léger et al., 1988) protocol has been previously recommended due to it having a higher mean criterion validity in comparison to other protocols (Mayorga-Vega et al., 2015). This section also shows the inconsistencies in the ways results are reported in different studies, making it more difficult to draw comparisons between groups and regions. All the studies compared with the MPBC dataset used researchers to carry out the testing in schools or transporting the children to laboratory or field facilities to carry out the tests, which is often done outside the curriculum. This can often encounter considerable costs and logistical challenges, which make such testing protocols less scalable than the MPBC method.

5.4.2 MPBC London and MPBC US comparison

This section of the chapter will discuss how it was possible to make comparisons and do a more thorough analysis when the same protocol and reporting measures were used, which was more limited when comparing MPBC London to other English studies.

The current study found that children in MPBC London had significantly higher levels of CRF when compared to their counterparts in MPBC US regardless of the CRF measurement (i.e. no. of shuttles, end speed, $\dot{V}O_{2peak}$, or z-scores). By reporting the results of CRF levels in the different methods age and sex were able to be accounted for, something that was limited when comparing to the other English studies.

The use of the quintile framework based on percentile categories derived by Tomkinson et al. (2017) provides the utility for both health and sport promotion, as they help identify children with:

1) Very low levels of CRF in order to set appropriate targets to improve their CRF, monitor longitudinal changes, and promote positive behaviours (i.e. PA and exercise promotion).
2) Very high levels of CRF which can help recruit them into appropriate sporting and athletic programmes.

The current study found that there were significant differences ($p < 0.05$) between the English and US schoolchildren (boys, girls and all children) in the “very low”, “high” and “very high” quintiles for levels of CRF, as well for girls in the “moderate” quintile for level of CRF. The largest differences were in the proportion of children categorised as having “very low” levels of CRF (MPBC London = 35.9%, MPBC US = 59.3%) and “very high” levels of CRF (MPBC London = 23.3%, MPBC US = 7.2%). This type of surveillance data provides a platform for countries to draw comparisons and to learn if the policies and programmes that are implemented may have benefits in their own country. Both cohorts were drawn from inner city schools in England and the US, yet the differences in proportions for those with the highest and lowest levels of CRF is particularly alarming for schools in the US. This may be related to SES of the children in the two cohorts, with the average eligibility of free school lunches only 23.8% in MPBC London, compared to 60.0% in MPBC US. However, the percentage of children in the Healthy Fitness Zone in the MPBC US cohort (boys = 57.9%, girls = 37.1%) was similar to those reported in the National Health and Nutrition Examination Survey (NHANES) National Youth Fitness Survey (NNYFS) in 2012 (boys = 50.2%, girls = 33.8%; Gahche et al., 2014), although the NNYFS only tests the CRF of children aged 12-15 years. Therefore, these findings suggest that interventions that aim to improve CRF in both countries, especially in the US, should focus on children who have the lowest levels of CRF.

There have not been any previous studies that have directly compared the CRF of children and youth between the England and the US previously. However, the findings of the current study agree with Lang et al. (2018b), who accumulated data from individual studies. Lang et al. (2018b) reported that the UK had a higher centile rank of 62 (z-score = 0.31 (95% CI = 0.30, 0.32), whereas the US had a centile rank of 32 (z-score = -0.47 (95% CI = -0.48, -0.46). The difference between the in CRF levels of children from England and the US found in the current study may be due to the localised samples of both cohorts, with the previous section of this chapter demonstrating how CRF can vary in different areas of different deprivation.

The current study's findings disagree with the scores the respective countries reported in the Healthy Kids Global Alliance's PA report cards, with both England and US scoring a C- in physical fitness (Katzmarzyk et al., 2018; Standage et al., 2018). The difference found in the current study may be explained partially by some of the other indicators in the report cards, with England scoring higher grades than the US in "overall physical activity" (England = C-, US = D-), "active transportation" (England = C-, US = D-) and "school" (England = B+, US = D-). However, there are still issues with using the report cards to compare CRF and PA between countries, with more detailed instructions for the indicators and benchmarks needed (Aubert, Barnes & Tremblay, 2020). For example, the US report card (Katzmarzyk et al., 2018) cited the source of their CRF data as the percentage of children in the Healthy Fitness Zone from the NHANES NNYFS (Gahache et al., 2014), whereas the England report card (Standage et al., 2018) cited data from the centile curves and normative values reported by Sandercock et al. (2012). As well as using different methods to determine a physical fitness grade from the CRF levels of children, the US and England report cards were also using data on children's CRF levels that was at least several years old (Gahache et al., 2014; Sandercock et al., 2012). To improve comparibility between countries using the report cards a basic set of common metrics for each indicator would be beneficial.

5.4.3 Strengths and Limitations

There are a number of strengths and limitations that need to be highlighted. A key strength of this study was that the CRF of children from MPBC London and MPBC US were analysed after completing the same protocol to provide an insight into the different CRF levels of children from the two countries. Additionally, both cohorts were reasonably large, of a similar age and from urban areas within developed countries. A further strength of the study was that international z-scores and quintile classification were used for a more in depth analysis. Another strength of this chapter was that the CRF of children from four regions in England which had varying levels of deprivation were compared. There are also several limitations within this chapter that need to be addressed. Firstly, SES was measured on a school level for the MPBC cohorts and the proportions of children eligible for free school lunches were different between MPBC London (23.8%) and MPBC US (60.0%). Therefore, analysis on whether deprivation had a significant impact on an individual level was not performed. Secondly, both MPBC cohorts were from inner city schools, London, Birmingham (Alabama), and Oakland (California). Therefore, it cannot be assumed that they are generally representative of the respective national populations. Thirdly, the lack of raw data, varying or not specified 20mMSR protocol and differences in methods used to report the summary data prevented a more in depth comparison of MPBC London with the other studies from England. All lead authors were contacted and sent requests for the summary data, yet this was not provided in the CCFAS project. Fourthly, not all regions of England were represented and compared within the study. For example, no studies were found within the South West region of England. Fifthly, the data from three of the four included in the national comparison section of this chapter were from several years ago; SportsLinx in 2010 (Boddy et al., 2012a), CCFAS in 2014 (Sandercock, Ogunyleye & Voss, 2015) and EEHHS 2006-2010 (Sandercock et al., 2012). Due to the downward trends found in children's CRF levels since the turn of the century in England and globally (Boddy et al., 2012a; Tomkinson et al., 2019b) these data may not represent the current CRF levels of children in their respective regions.

5.5 Conclusions

This chapter has provided an example of why CRF testing in schools should be adopted on a national scale. The first section of this chapter has highlighted how the data on the CRF levels of children in England is limited, with a lack of raw data available, difference in reporting methods, and data limited to certain regions, not to mention the lack of recent data. If CRF testing was adopted on a national scale using the same testing procedures and reporting methods, analysis between different regions, local authorities, and population groups across England would be possible. The second section of this chapter demonstrated how the implementation of a CRF testing programme can be implemented successfully in two different countries and provide an insight into the CRF levels of children in different countries.

Key Findings in Relation to Thesis

Study 1:

- The literature search performed in Study 1 highlighted that numerous studies do not measure CRF post-intervention. As highlighted in the literature review, CRF is an important health outcome that modifying PA behaviour aims to improve and should therefore be a routine measure post-intervention.
- The inclusion of measurements of CRF in studies of PA interventions in children is key to the evaluation of their impact. This study has demonstrated that inclusion of such outcomes facilitates the quantitative synthesis of effects to best understand the impact of PA interventions.
- Further, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that have utilised CRF testing as an outcome, the current study was able to examine this hypothesis.
- The lack of association between improvements in CRF with changes in executive function and academic performance therefore warrant no further research in this thesis.

Study 2:

- Study 2 found that it was difficult to draw comparisons with other studies that had measured CRF in England, with datasets limited to certain regions and non-existent in others. Further, the reporting methods in which the studies reported their findings varied, making it more difficult to draw comparisons between groups and regions. Therefore, England would benefit from adopting a standardised procedure to enable these comparisons to be made.
- Study 2 also demonstrated how feasible it would be to put in place the same CRF testing procedure in a different country and how the results could provide an insight into the CRF levels of children in each country.

CHAPTER 6.0 STUDY 3: CLASSIFICATION OF CARDIOMETABOLIC RISK IN PRIMARY SCHOOL CHILDREN BASED UPON BODY MASS INDEX OR CARDIORESPIRATORY FITNESS

6.1 Introduction

Currently, the only mandated measure of children's health status in England is the measurement of body mass index (BMI) by the National Child Measurement Programme (NCMP; National Health Service (NHS), 2019). The percentage of children that are overweight and obese in Reception Year (aged 4-5 years) and Year 6 (aged 10-11 years) are reported annually. However, BMI does not measure body fat percentage or distinguish between body fat percentage and fat-free mass (Nevill et al., 2006). Children are susceptible to having a skewed BMI due to muscle groups developing at different stages and growth spurts. Therefore, BMI should be interpreted with caution and be used as a guide (Cole et al., 2000). However, this highlights the need for another measure to monitor children's health status in England.

Cardiorespiratory fitness (CRF) is an important marker of cardiovascular health and provides a measure of both the cardiovascular and respiratory systems as well an individual's ability to undertake prolonged and exhaustive exercise (Ruiz et al., 2016). CRF levels in childhood and adolescence are associated with healthier cardiovascular profiles later in life (Ruiz et al., 2009; Case, Fertig & Paxon, 2005), and are a moderate to strong predictor of adult cardiovascular disease (CVD) and metabolic syndrome (Malina, 2001). The 20m Multistage Shuttle Run (20mMSR) is a commonly used method and considered the best field-based measurement of CRF in children because of the low cost, simplicity, and ability to test large groups of children simultaneously (Lang et al.

2018a; Castro-Piñero et al. 2010; Tomkinson et al. 2019b). In the past, the appropriateness and reliability of the 20mMSR has been questioned as it can be influenced by factors such as motivation (Naughton, Carlson & Greene, 2006), although motivation is an issue in all tests that require volitional effort. Regarding validity, a meta-analysis carried out by Mayorga-Vega et al. (2015) found that the 20mMSR had a moderate-to-high criterion-related validity for estimating the maximum oxygen uptake ($\dot{V}O_{2max}$) (r = 0.66-0.84). Mayorga-Vega et al. (2015) concluded in their meta-analysis that if a laboratory-based $\dot{V}O_{2max}$ test was not feasible then the 20mMSR was a useful alternative in estimating CRF. Previous studies have used the 20mMSR with children aged as young as 6 years (De Miguel-Etayo et al., 2014; Castro-Piñeiro et al., 2011). However, previous studies in England have focused on children in the older age-groups at primary school, aged 8 years and above (Weston, Pasecinic & Basterfield, 2019; Boddy et al., 2012a). Artero et al. (2011) found in their systematic review that the 20mMSR had a high-to-very high reliability (r = 0.78-0.93) for children aged 8-18 years. Therefore, children younger than 8 years should not be included in a study utilising the 20mMSR. There is still disagreement among researchers about the utilisation of the 20mMSR in youth populations. Recently, Armstrong and Welsman (2019) described in their editorial how 20mMSR performance scores are misrepresented as measures of CRF. In response, Tomkinson et al. (2019c) described how the 20mMSR has good feasibility, utility and scalability for population health surveillance to monitor trends and inform policy-making and public health planning. The 20mMSR was also identified in a systematic review as being the most scalable of children's fitness tests (Domone et al., 2016). Therefore, as a surveillance instrument to monitor children's CRF, the 20mMSR could identify populations with low CRF and inform policy or intervention practice (Lang et al., 2018a).

Recently, Ruiz et al. (2016) conducted a systematic review and meta-analysis into CRF cut-points and CVD risk in children and adolescents. Ruiz et al. (2016) found seven studies with children and adolescents from 14 countries that reported cut-points for CRF tests. Their meta-analysis found that fitness cut-points to avoid CVD fell between 41.8 and 47.0 $ml \cdot kg^{-1} \cdot min^{-1}$ in boys and 34.6 and 39.5 $ml \cdot kg^{-1} \cdot min^{-1}$ in girls, aged 8-17 years. In the UK, Boddy et al. (2012b) reported a cut-point in the 20mMSR that determined whether children aged 9.0-10.9 years were at an increased risk of cardiometabolic disease (CMD). The mean cut-point determined for the 20mMSR were 33 shuttles (peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$) = 46.6 $ml \cdot kg^{-1} \cdot min^{-1}$) for boys and 25 shuttles ($\dot{V}O_{2peak}$ = 41.9 $ml \cdot kg^{-1} \cdot min^{-1}$) for girls. Boddy et al. (2012b) found that participants classified as "fit" had significantly lower cardiometabolic risk (CMR) scores in comparison to those classified as "unfit" ($p < 0.001$). A further study by Housten et al. (2013) added support to the use of these cut-points as a method for identifying children at risk of CMD.

The potential issues with using BMI measurements as a sole determinant of health status in children, the development of cut-points that relate to increased risk of CMD and the importance of CRF in reducing CVD risk factors in obese individuals highlight the potential for routine measurement of CRF. Furthermore, there is the potential for children who are overweight or obese to have a health level of CRF. The "fat-but-fit" paradigm refers to those individuals whom in spite of being obese have a relatively good level of CRF. The term "fat-but-fit" was established later, but the two key studies supporting the concept were published in the late 1990s using data from the Aerobics Centre Longitudinal Study (ACLS; Wei et al., 1999; Lee, Blair & Jackson, 1999). The physiological explanation for the "fat-but-fit" paradigm is that people with higher levels of CRF have lower levels of most of the CVD risk factors, and this remains true within obese individuals, so that CRF is able to attenuate the effects of obesity on CVD risk factors and therefore reduce the risk of CVD mortality (Myers et al., 2015; Lavie, Archer, Shook & Blair, 2015). Specific information about the "fat-but-fit" paradigm in children and adolescents is lacking; yet, there is evidence suggesting that having a high level of CRF in youth may counteract the deleterious metabolic consequences attributed to an excess central and total adiposity (DuBose, Eisenmann & Donnelly, 2007; Mesa et al., 2006).

To the best of the thesis author's knowledge, no study has identified the percentage of English schoolchildren at an increased risk of CMD, as a result of their CRF level, in the different BMI weight categories. Therefore, the aims of this study were to analyse the relationship between BMI and CRF, and apply UK specific CRF cut-points to identify the percentage of English schoolchildren who were at an increased risk of CMD in the different BMI weight categories.

6.2 Methods

6.2.1 Participants and Settings

In the London boroughs of Camden and Islington 1,901 children from 17 of the 20 primary schools that were approached agreed to participate in the study. The children were in academic Years 4-6 aged 8-11 years. The participant characteristics (mean ± standard deviation (SD)) are shown in Table 6.1. The schools varied in deprivation with deprivation decile based on school postcode ranging from 1 to 9 (Ministry of Housing, Communities & Local Government 2019). The percentage of children entitled to free school meals at each school ranged from 0% to 40.5% (Education & Skills Funding Agency, 2018). Two schools were independent (private) schools whilst the remaining 15 were public schools. Data was collected between Autumn Term 2016 and Autumn Term 2018.

Table 6. 1 Participant Characteristics

	Boys	Girls	All
Age (years)	9.6 ± 0.8	9.5 ± 0.9	9.5 ± 0.6
[lower to upper]	[8.1-11.3]	[8.1-11.3]	[8.1-11.3]
Height (m)	1.38 ± 0.10	1.38 ± 0.11	1.38 ± 0.11
[lower to upper]	[1.11-1.72]	[1.09-1.78]	[1.09-1.78]
Mass (kg)	35.2 ± 8.8	34.9 ± 9.3	35.1 ± 9.1
[lower to upper]	[19.9-71.9]	[18.2-81.0]	[18.2-81.0]

Note: ± SD

6.2.2 Ethics

Approval was received from Coventry University's ethical committee (P60795: Appendix I). Informed consent and information sheets were sent out to headteachers and parents/guardians. Data from the children was only used if they had returned the signed informed consent. Headteachers, parents, and children were informed that they could withdraw from the study at any point.

6.2.3 Instruments and Procedures

In the present study, all testing was completed by Premier Education staff. This organisation had been previously identified by ukactive as being well placed to deliver the type of fitness testing described above on the large scale necessary as they were already situated in schools delivering 20mMSR as part of their core delivery.

6.2.3.1 Cardiorespiratory Fitness

Participants completed the 20mMSR using a lap scoring protocol based on the test developed by Léger et al. (Léger et al., 1984; Léger et al., 1988). Children completed the 20mMSR as part of the My Personal Best Challenge (MPBC) which has been described previously in Thesis Chapter 3.0 (Pages 68-70). The number of laps completed in the 20mMSR was used to determine whether each child in the study was above or below the cut-point that determined whether they were at an increased risk of CMD. Children were categorised as "unfit" and having an increased risk of CMD if they failed to reach the cut-point determined by Boddy et al. (2012b) for UK children (< 33 shuttles for boys, < 25 shuttles for girls). Age- and sex-specific fitness z-scores were calculated using the global reference values for children (Tomkinson et al., 2017).

6.2.3.2 Body Mass Index

Stature and body mass were measured and BMI calculated using procedures described in Thesis Chapter 3.0 (Pages 70-71). BMI z-scores were calculated specific to age and sex using the UK 1990 growth reference data (Cole, Freeman & Preece, 1995). International Obesity Task Force (IOTF) classifications were then established (Cole et al., 2000).

6.2.4 Design and Analysis

The kurtosis and skewness values for 20mMSR and BMI were assessed to identify whether each variable was normally distributed. The values for skewness and kurtosis were all between -1 and 1, and therefore met assumptions of normality of distribution (Kline, 2005), thus allowing parametric tests.

Descriptive statistics with means and standard deviations for continuous measures and the frequency distribution for categorical measures, were calculated by sex for preliminary analyses. All analyses were performed in IBM SPSS Statistics v.24 for Windows (IBM., Chicago, IL.). Significance levels were accepted at an α level of $p < 0.05$. The relationship between BMI z-scores and 20mMSR z-scores were examined using Pearson correlations. The 20mMSR z-scores were compared to the BMI z-scores because they are both normative-referenced standards. Independent t-tests were used to compare the BMI between groups formed by the 20mMSR cut-point. One-way analysis of variances (ANOVAs) were used to compare 20mMSR between groups formed by BMI categories (normal weight, overweight, and obese). Chi square statistics were used to analyse differences in proportions between 20mMSR cut-point groups (above or below cut-point) and dichotomised BMI categories (healthy weight and overweight/obese).

6.3 Results

Of the 1,901 children that were invited to participate in the study, 37 children did not participate in the fitness test or height and weight measurements. An additional 16 children did not participate in the 20mMSR, and 352 children did not complete the height and/or weight measurements, leaving 1,496 children that completed both the fitness test and height and weight measurements. The descriptive statistics shown in Table 6.2 and independent t-tests showed that the raw 20mMSR scores were significantly greater for the boys compared to the girls ($p < 0.001$). However, once the data was normalised using the z-scores there were no significant differences ($p = 0.731$). For BMI, there was no significant difference between boys and girls ($p = 0.920$), however boys had significantly greater BMI z-scores compared to girls ($p = 0.002$).

Table 6. 2 Descriptive Statistics

	Boys (n = 746)	Girls (n = 750)	Overall (n = 1,496)
Classified as "unfit" (%)	51.9	55.2	53.5
20mMSR (shuttles) ± SD	35* ± 21	28* ± 17	31 ± 19
20mMSR z-score ± SD	0.18 ± 1.25	0.15 ± 1.32	0.166 ± 1.28
BMI ± SD	18.27 ± 3.41	18.29 ± 3.63	18.28 ± 3.52
BMI z-score ± SD	0.62* ± 1.40	0.39* ± 1.38	0.51 ± 1.39
Overweight or Obese [Obese] (%)	40.2 [23.5]	33.6 [20.4]	36.9 [21.9]

**$p < 0.05$ between boys and girls*

This study found that 36.9% of children were overweight or obese with 21.9% being obese (Table 6.2). The Pearson correlation found a weak negative relationship between 20mMSR and BMI z-scores (r = -0.345, p < 0.001). The one-way ANOVAs found a significant between group effect in 20mMSR z-scores between the BMI weight categories for boys (F = 53.898, p < 0.001) and girls (F = 69.544, p < 0.001). Post-hoc pair wise comparisons analysis showed that boys and girls categorised as obese had significantly lower 20mMSR z-scores compared to all other BMI weight categories (p < 0.01). Boys and girls who were categorised as overweight had significantly lower 20mMSR z-scores than children categorised as normal weight (p < 0.001).

Regardless of their BMI weight category, 51.9% and 55.2% of boys and girls, respectively, were classified as unfit (Table 6.2). There was no significant difference between boys and girls in the percentage that were classified as unfit (χ^2 = 1.661 (df = 1), p = 0.108). Children who were overweight or obese were less likely to reach the 20mMSR cut-point compared with those who were healthy weight (boys = 69% compared to 40%, girls = 73% compared to 46%), shown in Figures 6.1 and 6.2. This was supported by the significant Chi-Square tests of independence for boys χ^2 (df = 1) = 58.935 (p < 0.001), for girls χ^2 (df = 1) = 50.905 ($p < 0.001$), and for boys and girls combined χ^2 (df = 1) = 107.353 ($p < 0.001$). Of all children who failed to reach the cut-point in the 20mMSR, 40.4% of boys (Figure 6.1) and 46.0% of girls (Figure 6.2) were classified as having a healthy BMI. The percentage of children who were classified as overweight or obese but met the cut-point in the 20mMSR were 12.5% and 8.9% for boys and girls respectively.

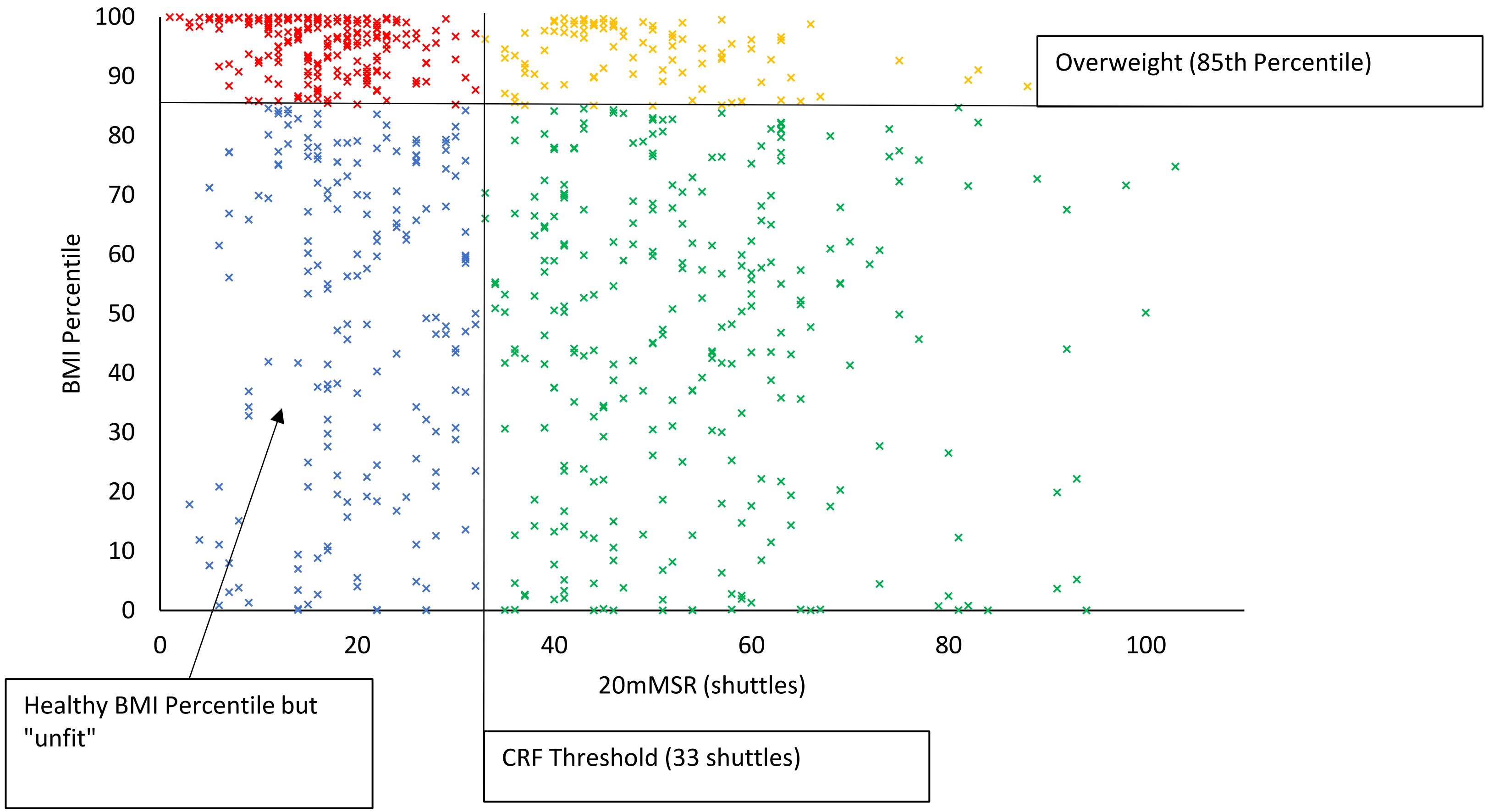

Figure 6. 1 BMI Percentile and 20mMSR performance of boys, with Overweight Percentile and CRF Cut-Point

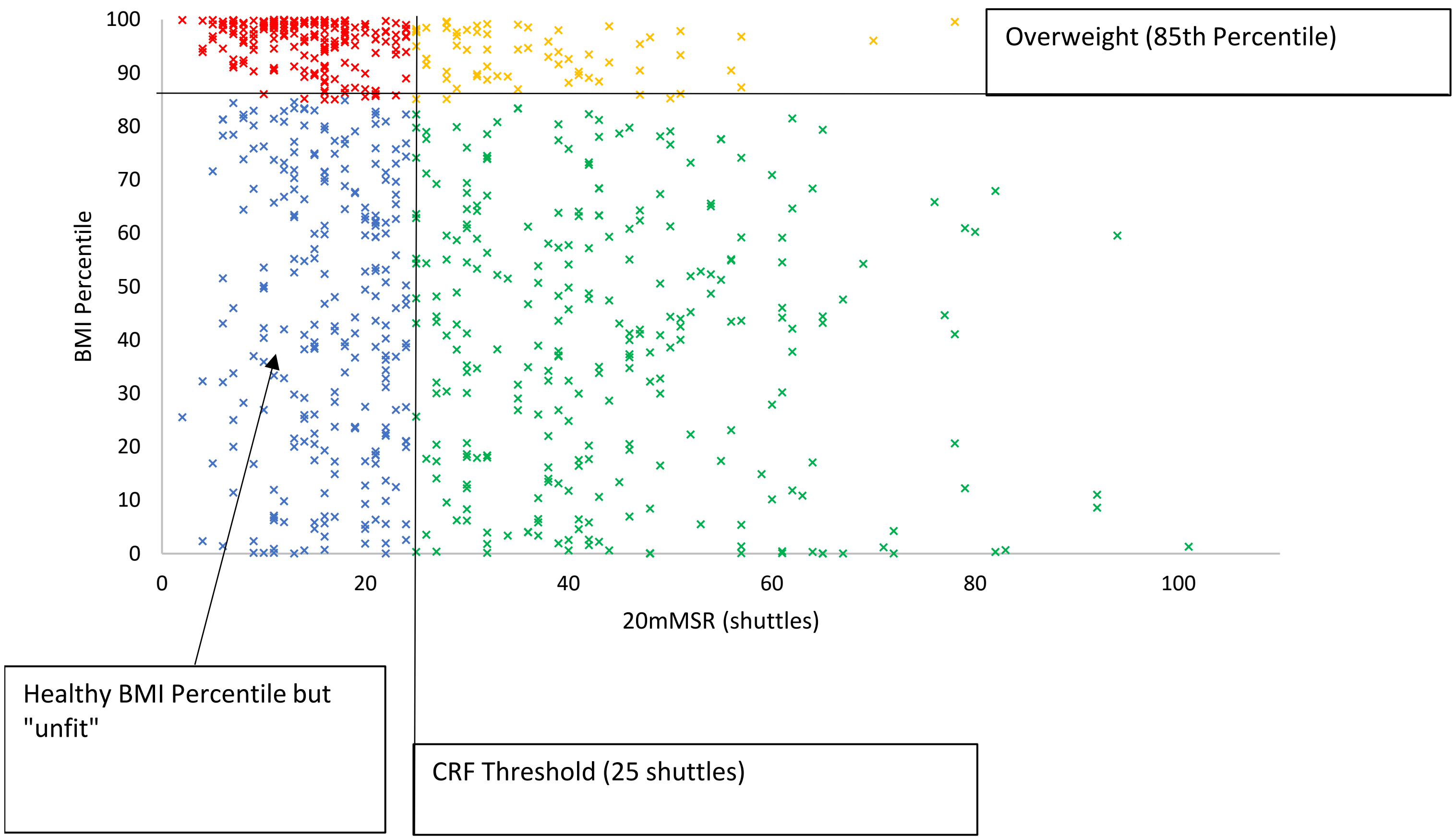

Figure 6. 2 BMI Percentile and 20mMSR performance of girls, with Overweight Percentile and CRF Cut-Point

6.4 Discussion

The aims of this study were to investigate the relationship of CRF and BMI and to identify the percentage of English schoolchildren who were at an increased risk of CMD when categorised by their BMI and CRF. The primary findings suggest that although there is a significant relationship between CRF and BMI and that there is a substantial proportion of children that may actually be at increased risk of CMD based upon the cut-points in the 20mMSR for British children in this age group as reported by Boddy et al. (2012b) who are either normal weight or overweight/obese.

The current study found that 51.9% of boys and 55.2% of girls were at an increased risk of CMD defined as failing to reach the cut-point in the 20mMSR (33 shuttles for boys and 25 shuttles for girls as reported by Boddy et al. (2012b)). Increasing CMR in the paediatric population is a global concern (Lloyd-Jones et al., 2009) and evidence demonstrates that CMR tracks from childhood into adulthood (Katzmarzyk et al., 2001). In order to effectively manage and reduce the proportion of children at risk of CMD, targeted interventions for "at risk" groups need to be introduced, especially when treatment of youth has been found to be more effective than treatment of adults (Epstein et al., 1995). Currently, the NCMP in England send the results and feedback of measurement to parents/guardians and schools. The current study had a similar proportion of children who were overweight or obese (boys = 40.2%, girls = 33.6%) compared to the NCMP who reported that 42.2% and 35.2% of boys and girls respectively were overweight or obese in England (NHS, 2019). If routine measurement of CRF was nationalised, parents/guardians of children with low CRF could similarly receive feedback and advice for "unfit" children as well as for children who are overweight or obese. Previous studies have shown that feedback from the NCMP given to parents about their child being overweight have often been dismissed (Gainsbury & Dowling, 2018; Syrad et al., 2015; Hughes & Timpson, 2014). Providing parents with feedback about an alternative health measure such as CRF may be received more positively. Including CRF assessment alongside BMI would also provide a more valid measurement of children's health status on a local authority and national level which would help inform policy. Other countries such as Slovenia and some states in the US collect data routinely on fitness in addition to BMI. For example, in Slovenia the data collected through SLOfit is used as a scientific platform for policies that are related to increasing the PA and decreasing the prevalence of obesity in children and adolescents (Jurak et al., 2019). Further, Dobbins et al. (2013) found that school-based interventions that significantly increased children's PA had no effect on children's BMI, whereas there were meaningful improvements in CRF. This suggests that CRF is a more sensitive measure to changes in PA than BMI and would therefore be a more effective tool to assess the impact of local or national interventions or programmes, as well as a useful tool for identifying which children are most at risk of CMD.

The "fat-but-fit" paradox suggests that having a higher level of CRF can attenuate the effects of obesity on CVD risk factors in adulthood (Myers et al., 2015; Lavie et al., 2015). Previous studies that investigated CMR and insulin resistance in children by comparing fitness and BMI category groups have shown that having high levels of fitness significantly reduces the risk of obesity-related comorbidities in each BMI category, including normal weight BMI groups (Moschonis et al., 2013; Nyström et al., 2017). The current study found that a proportion of boys (12.5%) and girls (8.9%) who were overweight or obese met the 20mMSR cut-point and these children could be categorised as "fat-but-fit". Moschonis et al. (2013) and Nyström et al. (2017) also highlighted that the CMR of children who were “fat-but-fit” was higher than children who were “lean-but-unfit”. Therefore, children categorised as “fat-but-fit” in the current study still need to be signposted to health interventions. However, the studies performed by Moschonis et al. (2013) and Nyström et al. (2017) used CRF percentiles (20th and 25th respectively) to categorise the children in their samples as unfit and not cut-points that were developed to determine whether children were at an increased risk of CMD. A concerning finding of the current study was the high proportion of children that failed to reach the cut-point in the 20mMSR who were categorised as having a healthy BMI (“lean-but-unfit”). The study found that 24.1% and 30.5% of boys and girls, respectively, were in this “lean-but-unfit” category. This demonstrates that a large proportion of children in England may be “missed” as being at greater risk of CMD if BMI was the sole measurement used. Therefore, these “lean-but-unfit” children who do not have a good level of CRF, may benefit from interventions aimed at increasing CRF as well as their overweight/obese peers.

The current study found significant but weak negative correlations between the BMI z-scores and CRF z-scores for boys and girls. This agrees with previous studies that have reported that overweight or obese children typically have lower levels of fitness but that the relationship is likely not strong (Morgan et al., 2013; Sandercock, Ogunleye & Voss, 2011). BMI has been shown to have a significant inverse relationship with fitness in some studies (Boddy et al., 2014; Sandercock, Ogunleye & Voss, 2011) and a non-significant relationship in others (Ostojic et al., 2011). These different findings between studies may be partly explained by the current study’s results, with 27.3% of children being “lean-but-unfit” and 10.7% of children being “fat-but-fit”. Even though significant correlations were found in this study, the correlations were weak, and it raises questions regarding the usefulness of BMI as the only measure to monitor the health status of children in England. Therefore, it may be beneficial to use an additional measure such as the 20mMSR to measure CRF, which has been associated with CVD risk factors in children and youth (Ortega et al. 2008a).

6.4.1 Strengths and Limitations

The major strength of this study was being able to apply cut-points to a relatively large sample of children. Additionally, these cut-points had been developed using children of a similar age and who were from the same country (Boddy et al., 2012b). Further, these cut-points have been validated in a second cohort within the UK (Housten et al., 2013). There are some limitations to this study that need to be acknowledged. Firstly, the cut-points devised by Boddy et al. (2012b) have not been validated longitudinally which may reduce their ability to predict morbidity. Secondly, date of birth was not provided for some children, and their date of birth was assumed as halfway through the academic year, meaning there could be up to a 6-month error in their age. This will have had a small impact on the normative BMI and CRF scores where age is used as part of the calculations. Thirdly, this research was conducted in inner London and generalisability to other countries or areas of England such as rural areas are unclear; although no significant differences were found in CRF levels between rural and urban children in England in a study conducted by Sandercock, Ogunleye and Voss (2011).

6.5 Conclusions

In conclusion, the present study has found a significant negative, but weak, correlation between CRF and BMI in children aged 8-11 years in England. Indeed, the results show that over half of children are at an increased risk of CMD due to low CRF, and that approximately a quarter of children are not being identified by current national measures based upon BMI as being at risk of CMD. These results highlight the need for fitness testing to be put in place alongside the current measures. Failing this, schools could be recommended to administer the 20mMSR themselves. This would allow improved monitoring of children's health and enable public health interventions to better identify and target those at risk. By improving the health of children via improving their CRF it may help predict and reduce the future non-communicable disease (NCD) burden.

Key Findings in Relation to Thesis

Study 1:

- The literature search performed in Study 1 highlighted that numerous studies do not measure CRF post-intervention. As highlighted in the literature review, CRF is an important health outcome that modifying PA behaviour aims to improve and should therefore be a routine measure post-intervention.
- The inclusion of measurements of CRF in studies of PA interventions in children is key to the evaluation of their impact. This study has demonstrated that inclusion of such outcomes facilitates the quantitative synthesis of effects to best understand the impact of PA interventions.
- Further, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that have utilised CRF testing as an outcome, the current study was able to examine this hypothesis.
- The lack of association between improvements in CRF with changes in executive function and academic performance therefore warrant no further research in this thesis.

Study 2:

- Study 2 found that it was difficult to draw comparisons with other studies that had measured CRF in England, with datasets limited to certain regions and non-existent in others. Further, the reporting methods in which the studies reported their findings varied, making it more difficult to draw comparisons between groups and regions. Therefore, England would benefit from adopting a standardised procedure to enable these comparisons to be made.
- Study 2 also demonstrated how feasible it would be to put in place the same CRF testing procedure in a different country and how the results could provide an insight into the CRF levels of children in each country.

Study 3:

- The findings in Study 3 suggest that the sole use of BMI to monitor children's health status may be limited, and that a substantial proportion of children who were categorised as having a healthy weight may actually be at an increased risk of CMD based upon their CRF levels.
- This strengthens the case for CRF testing in schools in England as this would enable public health interventions to better identify and target those at risk.

CHAPTER 7.0 STUDY 4: THREE-YEAR SURVEILLANCE OF CARDIORESPIRATORY FITNESS IN UK PRIMARY SCHOOL CHILDREN

7.1 Introduction

Cardiorespiratory fitness (CRF) and physical activity (PA) are closely associated, with moderate-to-vigorous PA (MVPA) the main modifiable influencer of CRF (Ortega et al., 2008b). However, CRF has been shown to be a stronger indicator of health than PA (Andersen et al., 2011). Therefore, identifying differences in CRF levels among children could indicate where services and interventions should be focused to improve health inequalities. The school setting can be used to improve and monitor the CRF of children and adolescents as they provide an environment where a large proportion of the youth population can be accessed for most of the year (Tomporowski, Lambourne & Okumara, 2011). However, despite recent calls (Lang et al., 2018a) there are only a few countries that are conducting such surveillance, including Hungary, South Korea, Japan, China, Slovenia, and some states in the US. In England, there have been several large-scale studies that have collected nationally representative samples of CRF, including studies by Sandercock, Ogunleye, and Voss (2015) and Boddy et al. (2012a). The most recent results of these studies were included in Study 2 (Thesis Chapter 5.0). Sandercock, Ogunleye, and Voss (2015) reported an annual CRF decline for children of 0.95% between 2008 and 2014, and Boddy et al. (2012a) reported an annual decline 0.4% between 1998 and 2010, whereas the global decline per decade is only 0.90% (Tomkinson et al., 2019b). The studies by Sandercock, Ogunleye and Voss (2015) and Boddy et al. (2012a) provide valuable insights at cross-sections of the country's CRF at different periods. However, there are few studies in England that have tracked CRF of children longitudinally using the same participants over a significant period. One study that monitored CRF changes over 12 months in England was performed by Mann et al. (2019). Mann et al. (2019) found significant improvements in children's CRF over the course of the academic year but then a significant decrease after the summer holiday period. This seasonal variation pattern has also been found in other countries with improvements that are made over the school year lost over the summer (Christodoulos et al., 2006; Carrel et al., 2007). However, recent work by Atkin et al. (2016) found that children are least active during the autumn and winter seasons, and Kornides et al. (2018) found that PA levels increase during the summer season. However, as previously mentioned CRF is most strongly related to vigorous PA (Santos et al., 2018). The study by Kornides et al. (2018) found that PA increased in the summer season due to an increase in moderate PA, and that the amount of vigorous PA was less. Therefore, if feasible a CRF surveillance project should consider a measurement either side of the summer holiday period (Mann et al., 2019).

Socio-economic status (SES) has been specifically highlighted as an environmental factor that affects children's CRF (Noonan et al., 2016; Noonan & Fairclough, 2018). The association between PA and CRF with SES is complicated, and this may partially be due to the varied measures of SES, PA, and CRF that have been used in the literature (Roberts et al., 2013). However, the results of Study 2 (Thesis Chapter 5.0) demonstrated that CRF was higher in areas of lower deprivation, such as Chelmsford in the East of England, compared to areas of higher deprivation such as the city of London or Liverpool in the North West of England. Furthermore, the association between SES and obesity prevalence in children is evident, with the National Child Measurement Programme (NCMP) reporting that the obesity prevalence of children in the most deprived areas (26.9%) was more than double the prevalence of children in the least deprived areas

(11.9%; National Health Service (NHS), 2019). Although, a recent study by Nevill et al. (2018) found that the association between obesity and SES was no longer significant when accounting for CRF, thus highlighting the importance of CRF in the association between obesity and SES.

There have been a number of studies in England and Wales that have considered SES and CRF in their analysis (Brophy et al., 2012; Charlton et al., 2014; Noonan et al., 2016; Nevill et al., 2017; Tyler et al., 2020). However, the aforementioned studies all had a cross-sectional design as did Study 2 (Thesis Chapter 5.0). Only one study conducted by Mann et al. (2019) reported how changes over a 12-month period differed between deprivation groups, who found that decreases in CRF over summer holidays was exemplified in children from more deprived areas. There has not been any study that has investigated changes in CRF over a period of longer than 12 months in England using the same participants or that has looked at how these trends may vary depending on SES. Therefore, the aims of this study are twofold. Firstly, to investigate the trends of CRF levels of primary school children over an extended time-period, with measurements either side of the summer holiday. Secondly, to investigate the effects of SES on these CRF levels over this period.

7.2 Methods

7.2.1 Participants and Settings

In the London boroughs of Camden and Islington 1,901 (age 9.4 years ± 0.8 years; height 1.38 m ± 0.10m; body mass 35.1 kg ± 9.2 kg) children, from 17 of the 20 primary schools that were invited, participated in the study. The children were in academic Years 4-6 aged

8-11 years. There were five rounds of data collection; Autumn Term 2016, Summer Term 2017, Autumn Term 2017, Summer Term 2018, and Autumn Term 2018.

7.2.2 Ethics

Approval was received from Coventry University's ethical committee (P60795). Informed consent and information sheets were sent out to headteachers and parents/guardians. Data from the children was only used if they had returned the signed informed consent. Headteachers, parents, and children were informed that they could withdraw from the study at any point.

7.2.3 Instruments and Procedures

In the present study, as outlined in the General Methods (Thesis Chapter 3.0), testing was administered by Premier Education staff.

7.2.3.1 Cardiorespiratory Fitness

To assess CRF, children completed the 20mMSR using a lap scoring protocol developed by Léger et al. (Léger et al., 1984; Léger et al., 1988). Further information can be found in Thesis Chapter 3.0 (Page 68-70). The global reference values were used to calculate age- and sex-specific age and sex specific z-scores (Tomkinson et al., 2017).

7.2.3.2 Body Mass Index

Stature was measured to the nearest 0.1 cm, and body mass was measured to the nearest 0.1 kg. Body mass index (BMI) was calculated from the height and mass measurements ($kg \cdot m^{-2}$). Age- and sex-specific BMI z-scores were calculated using the UK 1990 growth reference data (Cole, Freeman & Preece, 1995). Further details can be found in Thesis Chapter 3.0 (Page 70-71).

7.2.3.3 Socio-economic Status

The percentage of children entitled to the Pupil Premium (PP) at each school was used as a measure of school-level SES, a proxy for SES which has been used in previous studies (Mackintosh et al., 2011). The average percentage of children entitled to the PP across England is 13.9% (Education & Skills Funding Agency, 2018). The average in the boroughs of Camden and Islington was 24.6% and 25.8%, respectively, (Education & Skills Funding Agency, 2018), with an average of 25.2%. Therefore, children who attended schools that had more than 25.2% of their enrolled children entitled to the PP were classified as being from *"More Deprived"* schools and children who attended schools with less than 25.2% of their enrolled children entitled to the PP were classified as being from *"Less Deprived"* schools.

7.2.4 Statistical Analysis

Children were analysed across "age-group" which was in essence the time variable. Age-group was determined by the academic year of the child and the term that testing took place. For example, Year 4 Autumn (Y4A) included all children in academic Year 4 tested in an Autumn Term, though these children could have been tested in either Autumn Term 2016, 2017, or 2018. Year 4 Summer (Y4S) included all children who were in academic Year 4 and tested in the Summer Term of 2016 or 2017. This was repeated for children in Year 5 and Year 6 to generate six age-groups, as shown in Table 7.1.

Table 7. 1 Age-group and age of children

Age-group	Mean Age ± SD (years)
Year 4 Autumn Term (Y4A)	8.6 ± 0.3
Year 4 Summer Term (Y4S)	9.2 ± 0.3
Year 5 Autumn Term (Y5A)	9.6 ± 0.3
Year 5 Summer Term (Y5S)	10.1 ± 0.3
Year 6 Autumn Term (Y6A)	10.6 ± 0.3
Year 6 Summer Term (Y6S)	11.2 ± 0.3

The descriptive data is presented as means and standard deviations (SDs) for each age-group stratified by sex. Analysis for this study was treated as exploratory and was not pre-registered. For all analyses, the thesis author opted not to dichtomise the existence of effects and did not employ traditional null hypothesis significance testing, which has been extensively critiqued (McShane et al., 2019; Amrhein, Greenland & McShane, 2019). Although *p*-values were presented for the model summaries, the implications of all results (from the lower limit to the upper limit of interval estimates) that were compatible with these data were considered, with the greatest emphasis placed on the point estimates. Further, the focus was on qualitative description of the results after visual inspection of the data and models.

To account for both missing data (i.e. not having measurements for all six time-points for every participant) and the hierarchical structure of the data, linear mixed modelling was used. The 20mMSR raw scores (no. of shuttles) and 20mMSR z-scores were dependent variables. Linear mixed modelling recognises the existence of data in hierarchies by allowing for residual components at each level in the hierarchy. The data in essence had a 3-level structure with different individuals at different "age-groups" (i.e. time) nested within schools. The models were thus specified as growth models allowing for random intercepts (note there were insufficient observations to allow random slope structures) by school and participant (i.e. the values at time zero were allowed to vary between schools and participants) as:

Level 1

$$Y_{ijk} = \beta_{0jk} + \beta_{1jk}t_{ijk} + \epsilon_{ijk}$$

Level 2

$$\beta_{0jk} = \gamma_{00\mathrm{k}} + U_{0\mathrm{jk}}$$

$$\beta_{1jk} = \gamma_{10\mathrm{k}}$$

Level 3

$$\gamma_{00\mathrm{k}} = \delta_{000} + \delta_{001} + V_{0\mathrm{k}}$$

$$\gamma_{10\mathrm{k}} = \delta_{100} + \delta_{101}$$

Where *t* is the effect of age group (i.e. time). The thesis author also examined models of the interaction effects of sex (*s*) and SES (*SES*) thus formulating level 3 in these models as:

Level 3 (*s*)

$$\gamma_{00\mathrm{k}} = \delta_{000} + \delta_{001}s_k + V_{0\mathrm{k}}$$

$$\gamma_{10\mathrm{k}} = \delta_{100} + \delta_{101}s_k$$

Level 3 (*SES*)

$$\gamma_{00\mathrm{k}} = \delta_{000} + \delta_{001}SES_k + V_{0\mathrm{k}}$$

$$\gamma_{10\mathrm{k}} = \delta_{100} + \delta_{101}SES_k$$

Restricted Maximum Likelihood estimation was used in all models. Estimated marginal means were calculated and comparisons between the fixed factors were made using post-hoc Bonferonni adjusted tests where the 95% confidence intervals (CIs) were used to assess the differences. For independent groups, the two separate CIs were used to assess the differences. If the two groups' CIs just touch or do not overlap, there is reasonable evidence of a population difference, and that $p < 0.01$ approximately (Cumming & Finch, 2005; Cumming, 2009). If the two groups' CIs overlap by a moderate amount (up to half of the margin of error), there is some evidence of a difference, where $p < 0.05$ approximately (Cumming, 2014). For the repeated measures within groups, the CI on the mean difference was used where the CI did not contain 0 when $p < 0.05$ (Cumming, 2014). All analysis was conducted in R (v 4.0.2; R Core Team, https://www.r-project.org/).

7.3 Results

Descriptive statistics for raw 20mMSR scores and 20mMSR z-scores are reported in Table 7.2.

Table 7. 2 Means [95% CI] for boys and girls in each age-group.

	Age-group	Raw 20mMSR score (shuttles) [95% CI]	20mMSR z-score [95% CI]
Boys	Y4A (*n* = 309)	31 [27, 35]	0.08 [-0.17, 0.34]
	Y4S (*n* = 250)	33 [29, 37]	0.19 [-0.07, 0.45]
	Y5A (*n* = 419)	37 [33, 40]	0.31 [0.06, 0.55]
	Y5S (*n* = 274)	39 [35, 43]	0.34 [0.06, 0.61]
	Y6A (*n* = 494)	45 [41, 48]	0.59 [0.34, 0.83]
	Y6S (*n* = 186)	48 [44, 52]	0.58 [0.31, 0.86]
Girls	Y4A (*n* = 358)	25 [21, 29]	-0.02 [-0.27, 0.23]
	Y4S (*n* = 229)	27 [23, 31]	0.21 [-0.05, 0.47]
	Y5A (*n* = 416)	28 [24, 31]	0.17 [-0.08, 0.42]
	Y5S (*n* = 270)	27 [23, 31]	0.15 [-0.12, 0.43]
	Y6A (*n* = 507)	35 [31, 38]	0.57 [0.33, 0.81]
	Y6S (*n* = 195)	37 [33, 42]	0.74 [0.45, 1.02]

The estimated marginal means showed that there was a difference in 20mMSR raw scores by sex (mean difference [95% CI] = 9.0 shuttles [7.3, 10.6]), with boys (mean [95% CI] = 38.6 shuttles [35.1, 42.1]) performing better than girls (mean [95% CI] = 29.7 shuttles [26.1, 33.2]). Visual inspection of the 95% CIs for the estimated marginal means for the boys and girls raw 20mMSR scores show that there was some evidence of a difference between boys and girls in Year 4 (age-groups Y4A and Y4S), although there was reasonable evidence of differences between boys and girls in Year 5 (age-groups Y5A and Y5S) and in Year 6 (age-groups Y6A and Y6S; Figure 7.1).

The 95% CIs (Table 7.3 and Table 7.4) for the raw 20mMSR scores show that there was only an improvement between two consecutive age-groups, Y5S and Y6A for boys (mean difference [95% CI] = -5.7 shuttles [-9.9, -1.6]) and Y5S and Y6A for girls (mean difference [95% CI] = -7.4 shuttles [-11.5, -3.3]). There was reasonable evidence that boys categorised as having a high SES (mean [95% CI] = 43.2 shuttles [38.2, 48.2]) had higher raw 20mMSR scores than boys categorised as low SES (mean [95% CI] = 34.0 shuttles [29.2, 38.9]). This was also evident for girls, with girls categorised as having a high SES (mean [95% CI] = 34.2 shuttles [29.2, 39.3]) outperforming girls with a low SES (mean [95% CI] = 25.1 shuttles [20.2, 29.9]). The fixed and interaction effects are shown in Table 12.1 in Appendix V.

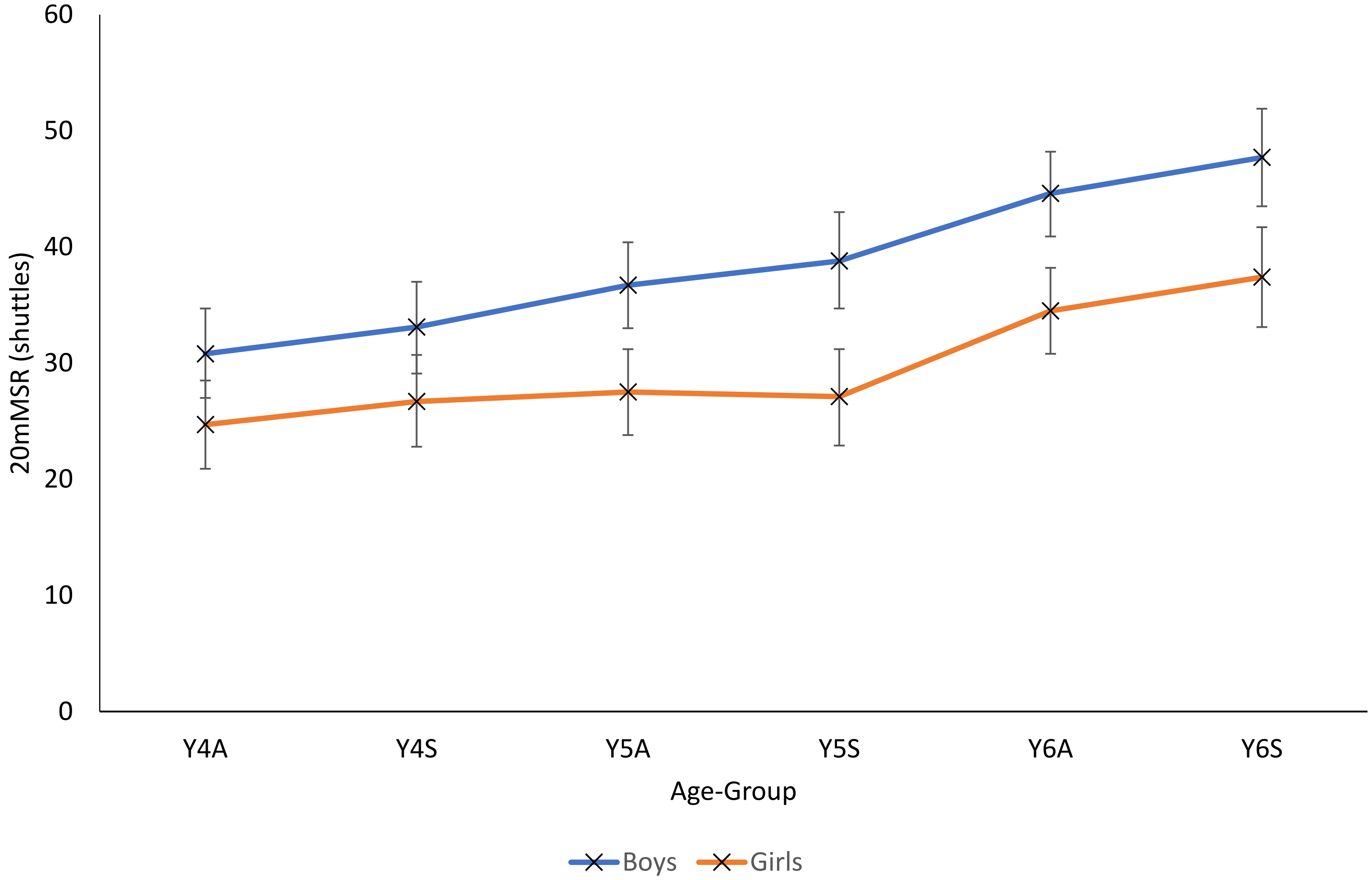

Figure 7. 1 Change in estimated marginal means with 95% CIs for raw 20mMSR scores across age-groups

Table 7. 3 Mean differences of raw 20mMSR scores and 20mMSR z-scores between age-groups for boys

(A) Age-group	(B) Age-group	Raw 20mMSR Score Mean Difference (A-B) [95%CI]	20mMSR z-score Mean Difference (A-B) [95% CI]
Y4A	Y4S	-2.2 [-5.9, 1.4]	-0.11 [-0.34, 0.13]
	Y5A	-5.9* [-9.5, -2.2]	-0.22 [-0.46, 0.01]
	Y5S	-8.0* [-12.8, -3.3]	-0.26 [-0.57, 0.05]
	Y6A	-13.7* [-17.3, -10.1]	-0.50* [-0.74, -0.27]
	Y6S	-16.9* [-21.8, -11.9]	-0.50 [-0.82, -0.18]
Y4S	Y4A	2.2 [-1.4, 5.9]	0.11 [-0.13, 0.11]
	Y5A	-3.6 [-7.5, 0.3]	-0.12 [-0.37, 0.13]
	Y5S	-5.8* [-10.7, -0.9]	-0.15 [-0.47, 0.17]
	Y6A	-11.5* [-15.3, -7.7]	-0.40 [-0.64, -0.15]
	Y6S	-14.6* [-19.7, -9.5]	-0.40 [-0.73, -0.07]
Y5A	Y4A	5.9* [2.2, 9.5]	0.22 [-0.01, 0.46]
	Y4S	3.6 [-0.3, 7.5]	0.12 [-0.13, 0.37]
	Y5S	-2.2 [-6.2, 1.9]	-0.03 [-0.30, 0.23]
	Y6A	-7.9* [-10.9, -4.8]	-0.28 [-0.48, -0.08]
	Y6S	-11.0* [-15.6, -6.4]	-0.28 [-0.58, 0.02]
Y5S	Y4A	8.0* [3.3, 12.8]	0.26 [-0.05, 0.57]
	Y4S	5.8* [0.9, 10.7]	0.15 [-0.17, 0.47]
	Y5A	2.2 [-1.9, 6.2]	0.03 [-0.23, 0.30]
	Y6A	-5.7* [-9.9, -1.6]	-0.24 [-0.52, 0.03]
	Y6S	-8.9* [-14.2, -3.5]	-0.24 [-0.59, 0.10]
Y6A	Y4A	13.7* [10.1, 17.3]	0.50* [0.27, 0.74]
	Y4S	11.5* [7.7, 15.3]	0.40 [0.15, 0.64]
	Y5A	7.9* [4.8, 10.9]	0.28 [0.08, 0.48]
	Y5S	5.7* [1.6, 9.9]	0.24 [-0.03. 0.52]
	Y6S	-3.1 [-7.2, 1.0]	0.00 [-0.27, 0.27]
Y6S	Y4A	16.9* [11.9, 21.8]	0.50 [0.18, 0.82]
	Y4S	14.6* [9.5, 19.7]	0.40 [0.07, 0.73]
	Y5A	11.0* [6.4, 15.6]	0.28 [-0.02, 0.58]
	Y5S	8.9* [3.5, 14.2]	0.24 [-0.10, 0.59]
	Y6A	3.1 [1.0, 7.2]	0.00 [-0.27, 0.27]

**No overlap of 95% CIs*

Table 7. 4 Mean differences of raw 20mMSR scores and 20mMSR z-scores between age-groups for girls

(A) Age-group	(B) Age-group	Raw 20mMSR Score Mean Difference (A-B) [95%CI]	20mMSR z-score Mean Difference (A-B) [95% CI]
Y4A	Y4S	-2.0 [-5.6, 1.5]	-0.23 [-0.47, 0.00]
	Y5A	-2.8 [-6.3, 0.6]	-0.19 [-0.41, 0.03]
	Y5S	-2.4 [-7.0, 2.2]	-0.17 [-0.48, 0.13]
	Y6A	-9.8* [-13.3, -6.3]	-0.59* [-0.82, -0.36]
	Y6S	-12.7* [-17.8, -7.7]	-0.76* [-1.08, -0.43]
Y4S	Y4A	2.0 [-1.5, 5.6]	0.23 [0.00, 0.47]
	Y5A	-0.8 [-4.6, 3.1]	0.04 [-0.21, 0.29]
	Y5S	-0.4 [-5.2, 4.5]	0.06 [-0.26, 0.38]
	Y6A	--7.7* [-11.6, -3.9]	-0.36 [-0.61, -0.11]
	Y6S	-10.7* [-16.0, -5.4]	-0.52 [-0.87, -0.18]
Y5A	Y4A	2.8 [-0.6, 6.3]	0.19 [-0.03, 0.41]
	Y4S	0.8 [-3.1, 4.6]	-0.04 [-0.29, 0.21]
	Y5S	0.4 [-3.6, 4.4]	0.02 [-0.25, 0.28]
	Y6A	-7.0* [-10.0, -3.9]	-0.40 [-0.60, -0.20]
	Y6S	-9.9* [-14.7, -5.1]	-0.57 [-0.88, -0.26]
Y5S	Y4A	2.4 [-2.2, 7.0]	0.17 [-0.13, 0.48]
	Y4S	0.4 [-4.5, 5.2]	-0.06 [-0.38, 0.26]
	Y5A	-0.4 [-4.4, 3.6]	-0.02 [-0.28, 0.25]
	Y6A	-7.4* [-11.5, -3.3]	-0.42 [-0.68, -0.15]
	Y6S	-10.3* [-15.8, -4.9]	-0.58 [-0.94, -0.23]
Y6A	Y4A	9.8* [6.3, 13.3]	0.59* [0.36, 0.82]
	Y4S	7.7* [3.9, 11.6]	0.36 [0.11, 0.61]
	Y5A	7.0* [3.9, 10.0]	0.40 [0.20, 0.60]
	Y5S	7.4* [3.3, 11.5]	0.42 [0.15, 0.68]
	Y6S	-3.0 [-7.3, 1.4]	-0.17 [-0.45, 0.12]
Y6S	Y4A	12.7* [7.7, 17.8]	0.76* [0.43, 1.08]
	Y4S	10.7* [5.4, 16.0]	0.52 [0.18, 0.87]
	Y5A	9.9* [5.1, 14.7]	0.57 [0.26, 0.88]
	Y5S	10.3* [4.9, 15.8]	0.58 [0.23, 0.94]
	Y6A	3.0 [-1.4, 7.3]	0.17 [-0.12, 0.45]

**No overlap of 95% CIs*

The estimated marginal means show that there were no differences in 20mMSR z-scores by sex (mean difference [95% CI] = 0.04 [-0.06, 0.15]), with similar overall means for boys (mean [95% CI] = 0.35 [0.11, 0.58]) and girls (mean [95% CI] = 0.30 [0.07, 0.54]). There was also no evidence of differences between boys and girls in each age-group, with considerable overlap of the 95% CIs in each age-group (Figure 7.2). The pairwise comparisons show that children in Year 6 (age-groups Y6A and Y6S) had higher 20mMSR z-scores than children in Year 4 (age-groups Y4A and Y4S; Table 7.3 and Table 7.4). There were no improvements between consecutive age-groups for boys and only an improvement between Y5S and Y6A (mean difference [95% CI] = -0.42 [-0.68, -0.15]) for girls (Table 7.3 and Table 7.4). The fixed and interaction effects are shown in Table 12.2 in Appendix V.

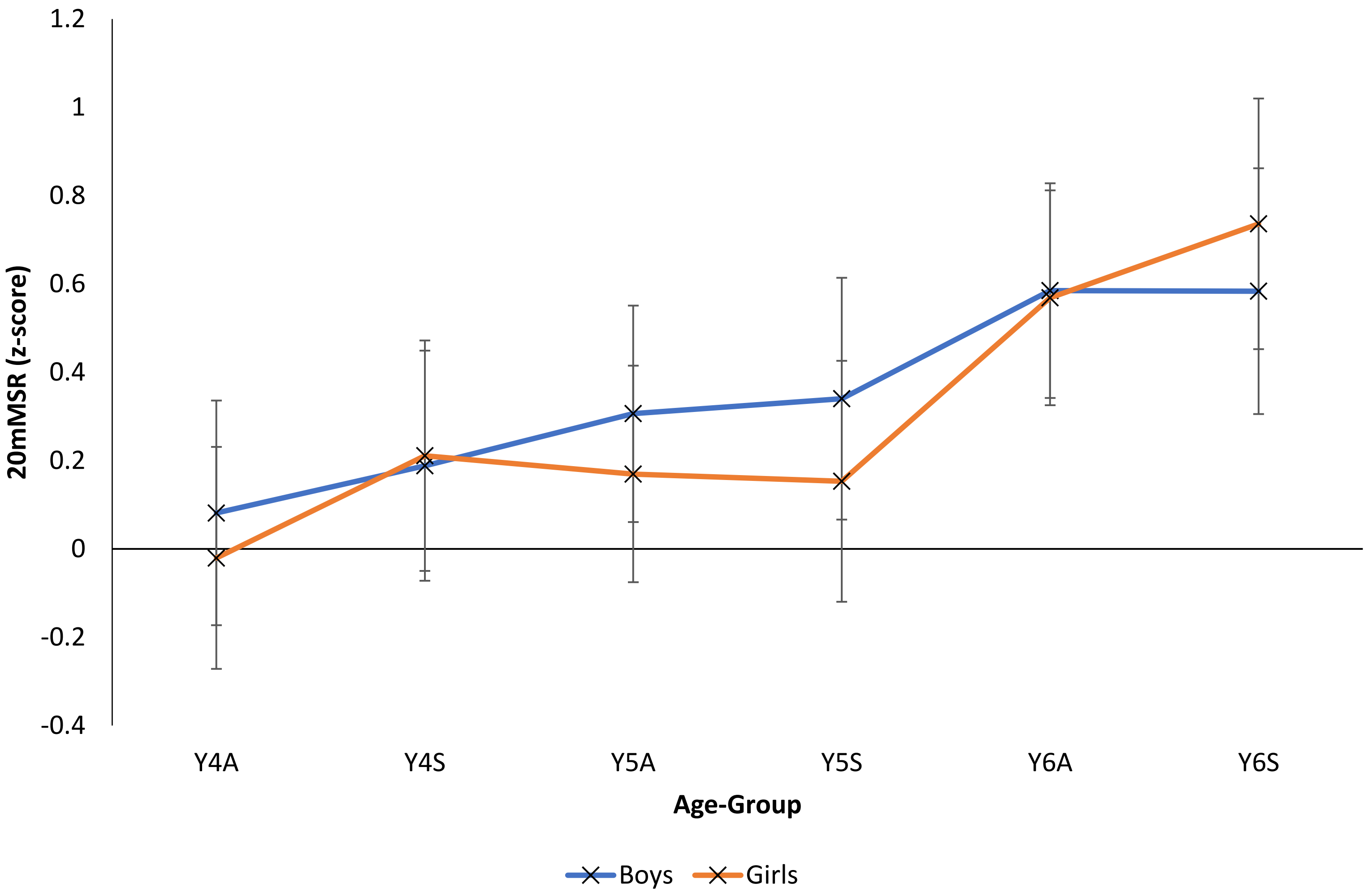

Figure 7. 2 Change in estimated marginal means with 95% CIs for 20mMSR z-scores across age-groups

The estimated marginal means show that there was reasonable evidence of a difference by SES category (mean difference [95% CI] = 0.64 [0.18, 1.1]) with children categorised as having a high SES having higher 20mMSR z-scores (mean [95% CI] = 0.65 [0.31, 0.98]) than children categorised as having a low SES (mean [95% CI] = 0.01 [-0.31, 0.32]).Visual inspection of the CIs in Figure 7.3 show that there is reasonable evidence of a difference between SES groups with children categorised as having a high SES having higher 20mMSR z-scores than children in the low SES group in the following age-groups; Y4A, Y4S, Y5A, Y5S and Y6A. However, there was no evidence of a difference between SES groups in age-group Y6S with considerable overlap between the CIs. There was a greater improvement in 20mMSR z-scores from the Y4A age-group to Y6S age-group in the low SES group compared to the high SES group (Figure 7.3). When tracking 20mMSR z-score between the age-groups, pairwise comparisons for high SES children found an improvement between two consecutive age-groups Y5S and Y6A (mean difference [95% CI] = 0.22 [0.01, 0.44]), shown in Table 7.5. For children categorised as low SES there were differences between the following consecutive age-groups; Y4A and Y4S (mean difference [95% CI] = 0.32 [0.05, 0.60]) and Y5S and Y6A (mean difference [95% CI] = 0.44 [0.09, 0.79]), shown in Table 7.5.

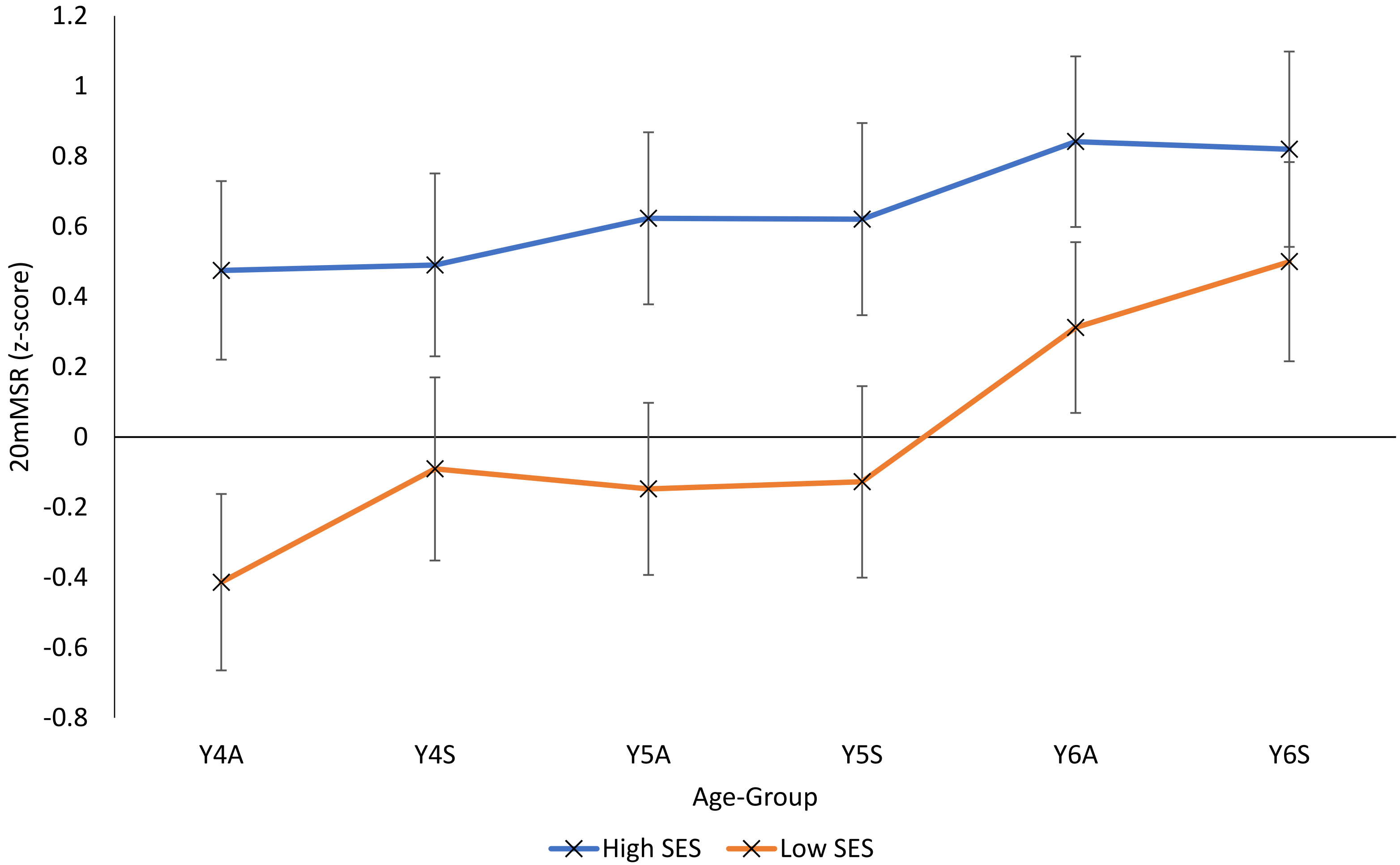

Figure 7. 3 Change in estimated marginal means with 95% CIs for 20mMSR z-scores scores across age-groups by SES group

Table 7. 5 Mean differences of 20mMSR z-scores between age-groups for high SES children

(A) Age-group	(B) Age-group	20mMSR z-score Mean Difference (A-B) [95% CI]	
		High SES Children	Low SES Children
Y4A	Y4S	-0.02 [-0.22, 0.19]	-0.32* [-0.60, -0.05]
	Y5A	-0.15 [-0.36, 0.06]	-0.27* [-0.52, -0.01]
	Y5S	-0.15 [-0.39, 0.10]	-0.29 [-0.68, 0.10]
	Y6A	-0.37* [-0.58, -0.15]	-0.73* [-0.98, -0.48]
	Y6S	-0.35* [-0.62, -0.07]	-0.91* [-1.31, -0.52]
Y4S	Y4A	0.02 [-0.19, 0.22]	0.32* [0.05, 0.60]
	Y5A	-0.13 [-0.34, 0.08]	0.06 [-0.25, 0.37]
	Y5S	-0.13 [-0.37, 0.11]	0.04 [-0.38, 0.45]
	Y6A	-0.35* [-0.57, -0.14]	-0.40* [-0.70, -0.11]
	Y6S	-0.33* [-0.60, -0.06]	-0.59* [-1.01, -0.18]
Y5A	Y4A	0.15 [-0.10, 0.39]	0.27* [-0.10, 0.68]
	Y4S	0.13 [0.08, 0.34]	-0.06 [-0.37, 0.25]
	Y5S	0.00 [-0.21, 0.21]	-0.02 [-0.36, 0.32]
	Y6A	-0.22* [-0.41, -0.03]	-0.46* [-0.67, -0.25]
	Y6S	-0.20 [-0.45, 0.06]	-0.65* [-1.02, -0.27]
Y5S	Y4A	0.15 [-0.10, 0.39]	0.29 [-0.10, 0.68]
	Y4S	0.13 [-0.11, 0.37]	-0.04 [-0.45, 0.38]
	Y5A	0.00 [-0.21, 0.21]	0.02 [-0.32, 0.36]
	Y6A	-0.22* [-0.44, -0.01]	-0.44* [-0.79, -0.09]
	Y6S	-0.20 [-0.47, 0.07]	-0.63* [-1.09, -0.17]
Y6A	Y4A	0.37* [0.15, 0.58]	0.73* [0.48, 0.98]
	Y4S	0.35* [0.14, 0.57]	0.40* [0.11, 0.70]
	Y5A	0.22* [0.03, 0.41]	0.65* [0.27, 1.02]
	Y5S	0.22* [0.01, 0.44]	0.44* [0.09, 0.79]
	Y6S	0.02 [-0.21, 0.25]	-0.19 [-0.52, 0.15]
Y6S	Y4A	0.35* [0.07, 0.62]	0.91* [0.52, 1.31]
	Y4S	0.33* [0.06, 0.60]	0.59* [0.18, 1.01]
	Y5A	0.20 [-0.06, 0.45]	0.65* [0.27, 1.02]
	Y5S	0.20 [-0.07, 0.47]	0.63* [0.17, 1.09]
	Y6A	-0.02 [-0.25, 0.21]	0.19 [-0.15, 0.52]

**No overlap of 95% CIs*

7.4 Discussion

While there have been several nationally representative studies that have reported the CRF levels of primary school children in England (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015), this is the largest project to track longitudinally the CRF of the same participants during the final years of primary school. The current study found that age-group, sex, SES, and BMI z-score all had effects on 20mMSR performance when reported in the raw format (no. of shuttles). When scores were normalised (z-scores), age-group, SES and BMI z-score still had an effect. Summarising the findings, when raw scores are examined, boys typically have greater CRF than girls, but when scores are normalised, there were no sex differences in CRF, demonstrating that the differences between boys and girls are similar to those expected for children in these age-groups. The current study found that children's absolute and normative CRF improved with age. Further, children at more deprived schools have lower CRF, especially younger children. However, by the end of primary school both low and high SES groups had similar CRF.

Sex differences in the raw scores were similar to what had been reported in other studies in England (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015) and globally (Lang et al., 2018b), with boys scoring outperforming girls in the 20mMSR. When compared across the age-groups, the difference in the raw 20mMSR performance between boys and girls increases as they get older. The underlying causes of the sex-specific differences are unclear for absolute measures of CRF, although they may be explained by physiological differences, for example, the fractional utilisation of oxygen and differences in mechanical efficiency (Armstrong & Welsman, 2007; Rowland, 2007). Once 20mMSR performance was adjusted for age and sex to produce the z-scores, sex no longer had an effect, and there were no differences between boys and girls in any of the age-groups.

The raw 20mMSR scores increased in each age-group, with children being able to run further as they develop (Werneck et al., 2019). However, there was also an increase between age-groups when normative data was used, so it was unlikely that maturation was the sole reason for this improvement in CRF. This is an interesting finding as the findings of serial cross-sectional measures studies conducted in England have shown a steady decrease of CRF for children in this age-group since the turn of the century (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015). These different findings may be due to several reasons. Firstly, many children may not have experienced a maximal fitness test prior to the test in this study and similar studies. Children who have not experienced a maximal fitness test might not be accustomed to running until volitional exhaustion and may become more familiar with the process and their bodies' responses in subsequent tests. This is a potential limitation of the current study as they did not complete a habitualisation session before completing their first fitness test. However, the results show that CRF continues to improve in subsequent tests as well, so this is unlikely to be the cause of the increase in CRF. Secondly, as is the case with all maximal fitness tests, motivation can have an influence on performance. However, the 20mMSR has been found to have high reliability (r = 0.78-0.93) and moderate-to-high validity (r = 0.66-0.84) in children and adolescents (Artero et al., 2011; Mayorga-Vega et al., 2015). Motivation may also be less of an issue in the 20mMSR as maximal effort is required at the end of the test compared to a test such as the one mile run which requires sustained near maximal intensity of effort throughout. Thirdly, the implementation of the testing was through the My Personal Best Challenge (MPBC). This encourages children to focus on their own previous scores and strive for a personal best each time they do the test, which was recommended by Sachek and Amin (2018) as a critical step to implementing CRF testing in schools. Finally, after becoming aware of their fitness level children may increase the amount of PA in their lives with the aim of improving their CRF, or reflect interventional effects of school based PA delivery. However, it is difficult in the present study to say for certain what resulted in the increase over time in 20mMSR z-scores.

The current study found no decrease in CRF over the summer holidays (between Y4S and Y5A, and Y5S and Y6A). However, there was an increase over the summer holiday period between Year 5 and Year 6. These findings disagree with those of a similar study in the North West of England who found a significant increase in CRF levels throughout the school year, with a decrease over the summer holiday period for students in Year 5 aged 9-10 years (Mann et al., 2019). The decrease in CRF over summer holiday periods has been previously attributed to a decrease in vigorous PA during the summer holidays compared to school days (Olds, Maher & Dumuid, 2019). Therefore, the increase in CRF in the current study over the summer holiday period may be due to an increase in vigorous PA during this period. However, the current study did not collect data on the activities children participated in over the summer holiday periods or monitor their PA.

The results of the 20mMSR z-scores when split by SES (Figure 7.3) suggested that younger children from more deprived areas had lower CRF levels than children from less deprived areas, which agrees with the findings of other studies in England (Nevill et al., 2018; Charlton et al., 2014; Mann et al., 2019). Interestingly, the difference between the two groups decreased, and by Y6S there was no difference in CRF. Due to the lack of studies with similar designs it is difficult to distinguish differences or make comparisons with this trend. One possible explanation is that high SES children may be attending schools which have more emphasis on PE and PA. All state-funded schools in England are recommended to provide children with a minimum of two hours PE per week. However, Office for Standards in Education (OFSTED) found that only 69% of schools visited as part of a study had two or more hours timetabled each week (OFSTED, 2018). Further, each school can decide what other activities are provided outside the children's curriculum PE lessons, and this can be restricted by staff's enthusiasm and commitment to PA, as well as available budgets. Many extra-curricular activities rely upon parents to contribute financially. Whether or not a child receives the PP depends on their parental income, this may prevent schools who have a higher percentage of children enrolled that are eligible for the Pupil Premium being able to provide extra-curricular activities. Another possible explanation is that as part of the project, each school was provided with annual reports with school and class level data, with comparison scores to the average fitness score in their area. This may have acted as an incentive for schools who were performing below the area average to try and increase the amount of PA provided at their school and improve their children's CRF. Studies that have focused on parental income and extracurricular use of sport facilities indicate that the participation of children from low income families is significantly less than those from high income families (Voss et al. 2008; Ziviani et al., 2008). Brockman et al. (2009) investigated the influences of SES on PA in primary school children in Bristol in England. Brockman et al. (2009) reported that time was a barrier to children from all SES groups, whilst cost was a significant barrier to children from low SES schools. Furthermore, Brockman et al. (2009) found that children from middle/high SES schools engaged in more sports clubs and organised activities, whilst children from low SES schools participated in more unstructured activities or "free play" with friends. Irrespective of the PA mode engaged in, any impact of SES upon engagement in PA appears more likely to influence children in early years. In Year 4 there is a substantial gap in CRF between deprived and affluent schools, yet this is no longer present upon leaving primary school in Year 6. Children from high SES areas may begin primary school having to a greater degree ‘optimised’ their CRF as a result of previous PA behaviours such that, though it increases over time from Year 4 to Year 6, this change is substantially smaller than that seen in children from deprived schools. Yet, children from deprived schools show a substantial change throughout primary school which may reflect a combination of PA delivery in these schools, low starting CRF, and subsequently a greater potential for improvement to occur. Indeed, schools in deprived areas may thus be providing sufficient opportunities for children to improve their CRF through PA. These differences between SES groups in changes over time also highlight the potential limitation of cross-sectional studies in examining whether deprivation level is associated with CRF.

This study has demonstrated how children’s CRF changes in the later stages of primary school education in England. However, there is still a debate in the academic community about whether fitness testing is appropriate in youth populations. Recently, Armstrong and Welsman (2019) published an editorial, criticising publications in journals such as the British Journal of Sports Medicine that used a field fitness test such as the 20mMSR, stating that it misrepresented and misinterpreted young people’s CRF which consequently misinformed health promotion and clinical practice. This was rebuked in a response to the editorial by Tomkinson et al. (2019c), who stated that the 20mMSR had a good feasibility, utility, and scalability for population health surveillance and to inform policy.

7.4.1 Strengths and Limitations

A strength of this study is that it was the first in England to take multiple measures of CRF from the same participants over an extended period. Most studies in England have applied a repeated measures design yet with different participants (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015). These studies are limited as they do not control for individual changes in CRF, instead providing population estimates from independent groups. Furthermore, previous longitudinal studies have used “last observation carried forward” approaches to missing data (Mann et al., 2019), linear mixed modelling in the present study accounted for unequal space and missing data value observations (Pusponegoroa et al., 2017). Another strength of the current study was that, despite the low sample size at some age-groups (*n* = 381 for Y6S, the smallest sample size), the sample size still compares favourably with similar studies in England (Sandercock, Ogunleye & Voss, 2015). There were, however, several limitations within this study. Firstly, most participants did not have data collected at all five time-points. This was due in part to children in Year 5 and Year 6 at baseline only being able to participate in four and two assessments, respectively. This was also due a lack of uptake for the testing programme at certain age-groups, mainly due to facility and time constraints. Secondly, the 20mMSR was used to measure CRF. However, the 20mMSR has been found as a valid, reliable, and scalable CRF test (Artero et al., 2011; Mayorga-Vega et al., 2015; Domone et al., 2016), particularly on a large scale like the current study where peak oxygen uptake measured in a laboratory would be impractical. Thirdly, this research was conducted in Inner London and generalisability to other countries or areas in England, such as rural areas are unclear; although no significant differences were found in CRF levels between rural and urban children in England in a study conducted by Sandercock, Ogunleye, and Voss (2011). Fourthly, the time of day in which the testing took place was not controlled and may have affected 20mMSR performance. Further, PA levels were not measured, so it was unclear if changes in CRF were mediated by changing PA levels particularly considering that school delivered PA interventions can improve CRF (as demonstrated in Thesis Chapter 4.0, Study 1). Finally, children were categorised as low or high SES based on their school's percentage of pupils that were entitled to the PP. This was a school-level measure but was used because individual participant-level data was not available.

7.5 Conclusions

In conclusion, by using CRF as a surveillance tool, this study found that children's CRF levels improve during the final years of primary school in England, after accounting for age, sex, SES, and BMI. This study has also demonstrated that children at more deprived schools have lower CRF, especially younger children. This particular finding warrants further investigation as it suggests that younger children may benefit from additional PA opportunities. However, by the end of primary school both low and high SES groups had similar CRF. This study adds evidence to how CRF surveillance projects can be utilised to help longitudinally monitor children's fitness levels over time and how they vary between different groups.

Key Findings in Relation to Thesis

Study 1:

- The literature search performed in Study 1 highlighted that numerous studies do not measure CRF post-intervention. As highlighted in the literature review, CRF is an important health outcome that modifying PA behaviour aims to improve and should therefore be a routine measure post-intervention.
- The inclusion of measurements of CRF in studies of PA interventions in children is key to the evaluation of their impact. This study has demonstrated that inclusion of such outcomes facilitates the quantitative synthesis of effects to best understand the impact of PA interventions.
- Further, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that have utilised CRF testing as an outcome, the current study was able to examine this hypothesis.
- The lack of association between improvements in CRF with changes in executive function and academic performance therefore warrant no further research in this thesis.

Study 2:

- Study 2 found that it was difficult to draw comparisons with other studies that had measured CRF in England, with datasets limited to certain regions and non-existent in others. Further, the reporting methods in which the studies reported their findings varied, making it more difficult to draw comparisons between groups and regions. Therefore, England would benefit from adopting a standardised procedure to enable these comparisons to be made.
- Study 2 also demonstrated how feasible it would be to put in place the same CRF testing procedure in a different country and how the results could provide an insight into the CRF levels of children in each country.

Study 3:

- The findings in Study 3 suggest that the sole use of BMI to monitor children's health status may be limited, and that a substantial proportion of children who were categorised as having a healthy weight may actually be at an increased risk of CMD based upon their CRF levels.
- This strengthens the case for CRF testing in schools in England as this would enable public health interventions to better identify and target those at risk.

Study 4:

- The findings in Study 4 provide further evidence of the benefits of regular monitoring of CRF levels in primary schools in England by tracking the CRF levels of the same children over a 3-year period. Study 4 found that children's normative 20mMSR scores increased with age and that SES had an impact on CRF levels.
- Study 4 demonstrates that if CRF testing was a regular procedure in schools, the data could be used as an evidence base to identify children, schools, or groups (e.g. sex or SES group) that would benefit from additional PA opportunities.

CHAPTER 8.0 STUDY 5: RETROSPECTIVE EXAMINATION OF TEACHERS' PERCEPTIONS OF FITNESS TESTING DELIVERY IN PRIMARY SCHOOLS THROUGH SEMI-STRUCTURED INTERVIEWS

8.1 Introduction

This thesis has demonstrated a number of the benefits of fitness testing in schools, including that it can be used: as a tool to evaluate interventions; to identify children at an increased risk of cardiometabolic disease (CMD); to track children over time and how these trends may differ between groups; and to make cohort comparisons nationally and internationally. However, there is still a debate within the academic community regarding the appropriateness of specific field fitness tests, such as the 20m Multistage Shuttle Run (20mMSR), to assess cardiorespiratory fitness (CRF) in youth populations (Armstrong & Welsman, 2019; Tomkinson et al., 2019c). Furthermore, the Association for Physical Education (PE; 2020) have criticised plans for fitness testing of primary school children in England, echoing concerns from academic literature (Naughton, Carlson & Greene, 2006). One specific concern is that overweight children may have unpleasant or embarrassing experiences (Association for PE, 2012). This may lead to or reinforce poor physical self-concept, with some studies showing that there may be negative psychosocial consequences (Martin et al., 2010; Zhu et al., 2010). Furthermore, fitness testing has been criticised for not promoting physical activity (PA; Cale, Harris & Chen, 2007). However, even those in favour of fitness testing in schools do not regard promotion of PA as an expected outcome (Cooper, 2010). For example, in another surveillance project in England, the National Child Measurement Programme's (NCMP) objective is to "inform local planning and delivery of services to children", not weight loss (Ridler et al., 2009).

A study by Cale, Harris and Chen (2014) found that fitness testing was commonplace within English secondary schools' PE curriculums when they interviewed Heads of PE (Cale, Harris & Chen, 2014). However, Cale, Harris and Chen (2014) did not report the teachers' perceptions of fitness testing but investigated how it was used. Previous research has shown that teacher perceptions and behaviours are closely related (Block & Obrusnikova, 2007). Therefore, it is important to understand teachers' opinions regarding fitness testing. In the US, where routine fitness testing is common in a number of states, teachers had a positive attitude towards fitness testing (Miller et al., 2016). Miller et al. (2016) found that as well as enjoying the fitness testing process, teachers used the results to help students with goal setting and tracking students' progress. However, this disagrees with findings of a study in the UK (Harris and Cale, 2007). Harris and Cale (2007) found that there were mixed views from their participants on the fitness testing of children; potential benefits included the provision of baseline data to inform policy, and potential issues included negative effects on children's self-esteem or confidence and the limited validity and reliability of some fitness tests that stem from factors that could affect children's performance (e.g. hereditary, maturation, motivation, environment, protocol, child's intellectual and mechanical skill at taking the test). However, the study by Harris and Cale (2007) did not focus solely on teachers and included representatives from universities in Wales and England, PE advisory/inspection service, primary and secondary school teachers, the Sports Council for Wales, and the Welsh Assembly.

The findings presented in Studies 1 to 4 have provided several reasons why CRF testing should be implemented in primary schools in England. These studies present quantitative research and applications of how CRF data can be utilised. However, a more in-depth analysis is required to consider the views of teachers who oversee the PE delivery at primary schools. Such analysis may add further considerations to whether fitness testing should be implemented in primary schools in England and provide additional recommendations for future projects.

Since the study by Harris and Cale (2007) there has been no other study to date that has assessed primary school teachers' perceptions of fitness testing of children. Therefore, the aims of this research are twofold: firstly, in light of their participation in the My Personal Best Challenge (MPBC), to examine teachers' perceptions of CRF testing in primary schools; and secondly, to analyse the feedback from teachers on the MPBC specifically.

8.2 Methods

8.2.1 Participants and Settings

In total, 17 primary schools had taken part in the MPBC in the London boroughs of Camden and Islington in England. The member of staff at each primary school who was the main point of contact throughout the project was invited, via email or telephone call, to take part in a semi-structured telephone interview. The member of staff was either the primary school's PE teacher or PE coordinator. From the seventeen schools that were contacted, 12 teachers expressed an interest in taking part in the interview. However, due to the time constraints and other work commitments, only seven teachers confirmed and provided written informed consent to take part in the semi-structured interviews. Of the seven teachers who took part: four were male and three were female; five taught at regular, community public schools, and two taught at independently funded, private schools. The telephone semi-structured interviews took place between April and May of 2019.

8.2.2 Ethics

The seven teachers agreed to take part in the semi-structured interviews and provided written informed consent to take part in the study. All procedures were approved by the Coventry University Ethics Committee (P82273: Appendix III).

8.2.3 Instruments and Procedures

All semi-structured interviews were conducted by the thesis author in a non-directive and unbiased way (Gibson, 2007). Sample questions from the semi-structured interviews are provided in Table 8.1. At the start of each telephone interview, verbal consent was also obtained, by reading a summary of the information sheet and asking each participant if they had any questions and still agreed to participate. The telephone semi-structured interviews were recorded on two devices; a Dictaphone (primary recording method), and a tablet (using voice recording application "Voice Recorder & Audio Editor"). The version on the tablet was deleted as soon as the version on the Dictaphone had been verified as being successful. Participants were asked questions about their opinions on fitness testing in primary schools, and their experiences with the MPBC. All pre-determined questions were reviewed and discussed by the thesis author and supervisory team. The semi-structured interviews lasted approximately 25-45 minutes.

Table 8. 1 Example of semi-structured interview questions

Topic	Examples
Perceptions of fitness testing	What are your thoughts on fitness testing of children in primary schools?
Perceptions of fitness testing	How could we minimise these potential issues with fitness testing of children?
MPBC feedback	Why did you decide to take part in the MPBC?
MPBC feedback	What were your experiences taking part in the MPBC?

8.2.4 Data analysis

All interviews were transcribed verbatim resulting in 64 pages of raw data, Times New Roman font, size 12, double-spaced. The transcripts were thematically analysed using three steps: data immersion, coding and identifying themes (Braun & Clarke, 2006). Data immersion was completed in an active way of "repeated reading" of the transcripts and searching for meanings and patterns within the data (Braun & Clarke, 2006). A manual "cut and paste" technique was used for the coding process (Braun & Clarke, 2006). Key themes were then identified by collating the relevant coded data quotes and discarding irrelevant quotes from the analysis (Braun & Clarke, 2006). Frequency counting tables were used to process the data as this allowed the analytic generalisation of findings (Sandelowski, 2001). The frequency counts enabled the development of patterns and deviations within the data to be recognised more easily (Kim & Kuljis, 2010). The themes, frequency counts, and quotations were then displayed using a pen profile approach (Mackintosh et al., 2011; Crossley et al., 2019; Winn et al., 2018). There has been a debate in the health literature on the methods adopted in qualitative studies to improve our understanding of PA and other health behaviours (Allender, Cowburn & Foster, 2006;

Crossley et al., 2019). The need for different methodologies and analysis procedures within qualitative research has been described previously (Dale, 1996; Biddle et al., 2001; Ridgers, Knowles & Sayers, 2012). It has been demonstrated that the transferability of the study is not directly influenced by the analytical approach adopted, whether this is through manual tagging, "cut and paste" techniques in word processing data files, or specialist qualitative data analysis packages such as NVivo (Krane, Andersen & Strean, 1997). Pen profiles are considered to be a useful technique for researchers who have both qualitative and quantitative backgrounds (Krane, Andersen & Strean, 1997). Pen profiles have been used previously in studies exploring the perceptions and experiences of PA in both youth and adults (Knowles et al., 2013; Mackintosh et al., 2011; Crossley et al., 2019). The process of reverse triangulation was implemented, where the researchers critically questioned and examined the data in reverse from the pen profiles to the transcripts. This process was then repeated to allow for alternative interpretations of the data until an agreement on the final pen profile was reached. The triangulation process allows the data's findings to be tested for robustness using a 'trustworthiness criterion' (Ridgers, Knowles & Sayers, 2012). This criterion places trust in the researcher responsible for the data collection to determine which findings are noteworthy and in need of attention. Verbatim transcription and triangulation procedures afford the study credibility and transferability and comparison of the quotes and pen profiles adding to the dependability. Data saturation was assessed using the approach described by Guest, Namey and Chen (2020). A 'base size' of four interviews, 'run length' of two interviews and a 'new information threshold' of $\leq 5\%$ was used to determine data saturation.

8.3 Results

The proportion of new information added by run 1 (interviews 5 and 6) and run 2 (interviews 6 and 7) was below the ≤ 5% threshold (Figure 8.1). Since the last three interviews did not add substantially to the body of information collected it can be concluded that data saturation was reached after four interviews.

Saturation point at ≤5% threshold:

Interview Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
New themes per interview	24	16	11	4	1	0	1
New themes in run				**55**		1	1
% change over base						1.8%	1.8%

Base of 4

Runs of 2

Figure 8. 1 Data saturation assessment at base size 4 and run length 2

Two separate pen profiles were constructed to represent teachers' perceptions about CRF testing in primary schools (Figure 8.2), and teachers' feedback about the MPBC (Figure 8.3). Participant quotes are labelled in text with participant number, sex of the participant (M = male, F = female) and the type of school the participant taught in (S = state school, I = independent school), e.g. 1MI.

8.3.1 Teachers' perceptions on cardiorespiratory fitness testing in primary schools

The key emergent themes were structured around advantages, disadvantages, minimising disadvantages, key people needed to support CRF testing in schools and being in favour of mandatory CRF testing in schools (Figure 8.2).

All the teachers described how fitness testing can benefit children. An example of this was that it provides the children with an opportunity to set goals and targets for themselves (*n* = 7).

"…regular [fitness] *testing helps give them targets, gives them figures to work towards, we work through and discuss it."* (1MI)

"I think it gives children a goal, so when they come back to doing the fitness test a second time round, they really want to beat their last score. So, I think it gives them something to strive for." (4FI)

Another advantage highlighted by the majority of the teachers (*n* = 6) was how fitness testing raises the awareness about the children's fitness levels. Several of the teachers (*n* = 4) went even further and suggested that becoming aware of fitness levels may be motivation to do more PA.

"I think it allows them [the children] to challenge themselves and be more honest about where they are at and maybe where they want to get to, and also learning from their peers, and developing more of an awareness of themselves in a way. This may lead them to look at their own lifestyle choices and what they do themselves." (2MS)

As well as the benefits to the children, several of the teachers (*n* = 4) also described how fitness testing was useful to themselves and used it as a method of talent identification.

"We, as a school find this data quite useful. We do a cross-country event like every year, so I kind of use that information to help me sort of whittle down who potentially could go." (2MS)

However, only one teacher added that they would use the data to identify children who would benefit from extra support.

"It can be used to target children who need extra support, whether that's free clubs before or after school, contacting the parents to try and encourage them to get involved, to provide in school sessions." (3MS)

There were fewer common examples in the higher order theme 'Disadvantages' with the teachers finding it more difficult to come up with examples. However, one disadvantage that was highlighted by several of the teachers (n = 5) was that fitness testing might not be enjoyed by all children, and two teachers also described how children who drop out of the 20mMSR at a low level can be waiting around.

"I could see that if there was someone who was not very active outside of school feeling a little bit, you know, down on it." (6MS)

"The students who finish the test tend to get rowdy and don't like waiting for their classmates to finish." (7FS)

Teachers were then asked about how these negative effects could be minimised. Two teachers described generically the importance of the delivery method. Furthermore, two other teachers described specifically how grouping by ability would reduce these negative effects.

"I think if they did it in their own little group it would be a healthier competition, so that they are competing against children of more similar abilities." (2MS)

There were mixed opinions from the teachers when it came to who needed to support the implementation of fitness testing in primary schools. The two teachers from independent schools and one teacher from a state school described how the PE teacher or PE lead is the most important person when it comes to schools implementing fitness testing.

"I think it is more at the Sport Lead level." (1MI)

However, the majority of the teachers from state schools (*n* = 4) described how the headteacher or Office for Standards in Education (OFSTED) needed to provide backing and support for fitness testing to be implemented successfully in their schools and this was supported by one of the teachers from an independent school.

"…it's key the head is completely behind it." (3MS)

"I mean I'm kind of allowed to do what I want, you know, I would have a conversation with the headmistress. But I guess for the state schools it would have to be higher than that as they have so many things they need to check off. So, I think for state schools it would be more likely to be OFSTED." (4FI)

The final emergent theme was that the majority of teachers (*n* = 5) were in favour of mandatory fitness testing in primary schools. Two of the teachers described how they believed this would provide parents additional information about their child's activity levels (*n* = 2).

"I think it's important that parents are aware of where children are [in terms of fitness] *and how much activity their children are getting."* (1MI)

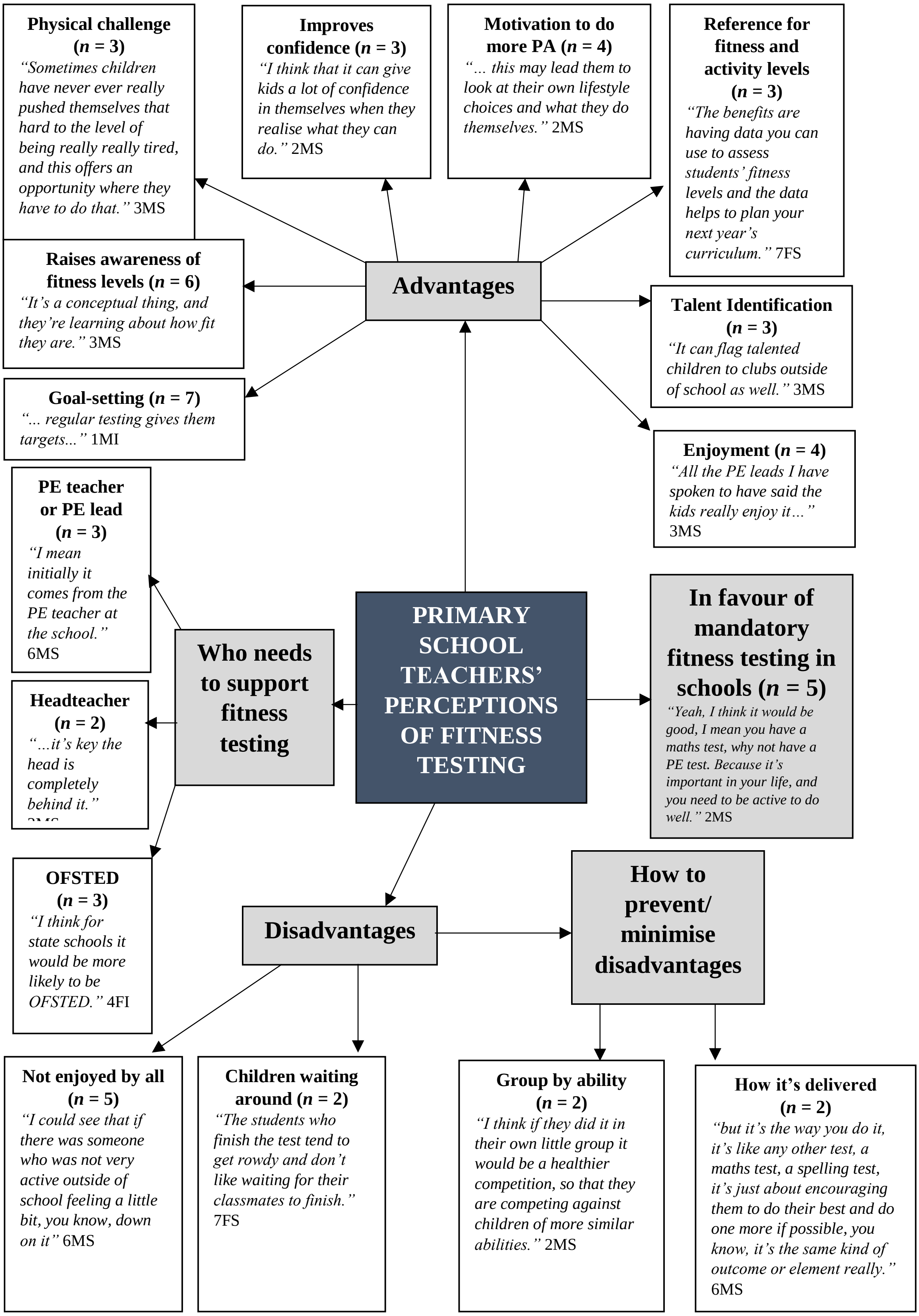

Figure 8. 2 Pen profile of teachers' perceptions of fitness testing in primary schools

8.3.2 Teachers' feedback on MPBC

When teachers were asked about the MPBC, the key emergent themes included the reasons why they chose to participate in the MPBC, their experiences with the project, issues they had had with parents and the children's enjoyment (Figure 8.3).

The teachers described how their motives for taking part in the MPBC were to gain an understanding of their own pupils' fitness levels (n = 4) and also to compare the fitness levels of children in their school to other schools in the area (n = 3).

"I know we're a tiny school, but it's interesting to see what we should be striving for, and what is the average, and how are we doing compared to that average." (4FI)

The majority of the teachers (n = 6) said they found taking part in the MPBC a positive experience overall. A sub-group theme described by two teachers as part of their positive experience with the MPBC was the 'Background and presentation'.

"… we then had a couple people come in and talk about the results which was really interesting." (4FI)

Some of the teachers (n = 2) also reported that the Premier Education staff who delivered the sessions made the MPBC a positive experience.

"The last guy was really good and really encouraging and the girls thought he was great." (4FI)

However, not all teachers found that the Premier Education staff made it a positive experience, with some stating they were not happy with the Premier Education staff (n = 2).

"… it was just one person and it was really unorganised, so we had to get a TA to help out, which we were happy to do." (6MS)

Another part of the MPBC that teachers described as a negative was the consent form process (*n* = 2).

"I think having to do the consent forms is a potential issue, because even if you have some parents who don't mind it, them completing the form may not happen." (3MS)

In the emergent theme 'Issues with parents' teachers had mixed experiences; some had no complaints from parents (*n* = 3), whilst others did have a few parents who were concerned and did not want their child to take part (*n* = 2).

"We did have a couple [of parents] *who didn't want to consent to their child doing it, but nothing else apart from that."* (2MS)

A key emergent theme from several of the teachers' feedback was that most children enjoyed participating in the MPBC (*n* = 5).

"On the whole, they all seemed pretty happy to do the test. A positive experience for most of them I'd say." (1MI)

Finally, teachers described how they would improve the MPBC. Two sub-themes emerged, including using a fitness test battery to test the different components of physical fitness (*n* = 2), and grouping the children by ability when administering the 20mMSR (*n* = 2).

"…doing a broad range of fitness testing to collect information on the other components of fitness, maybe doing some aerobic testing and anaerobic testing in some sort of way." (2MS)

"I also think that highlighting how well ability grouping seems to work with my own testing should be considered in future." (3MS)

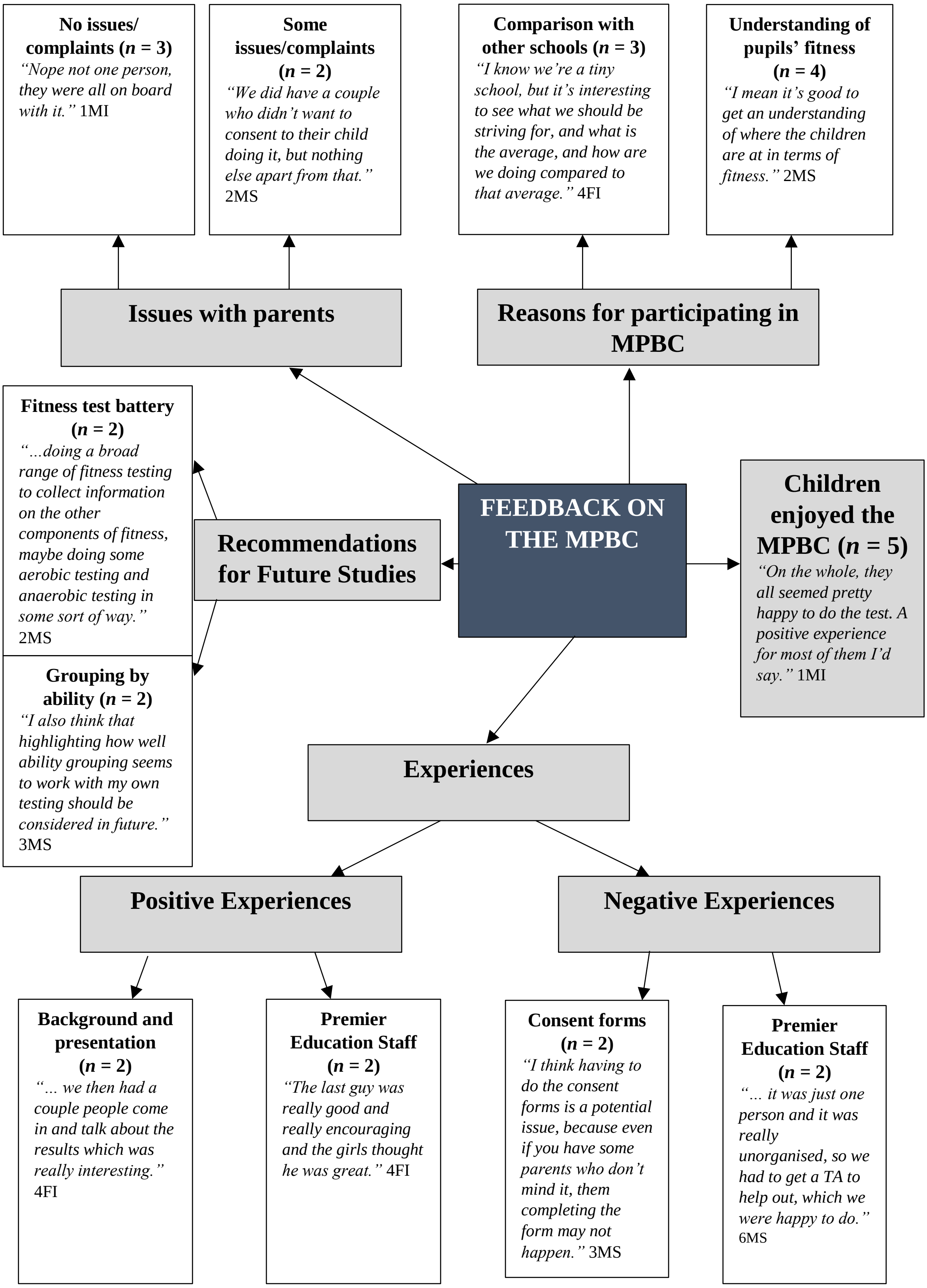

Figure 8. 3 Pen profile of teachers' feedback on the MPBC

8.4 Discussion

The aims of this research were, first, to formatively elicit teachers' perceptions of CRF testing of children in primary schools, and second, to analyse feedback from teachers on the MPBC.

8.4.1 Perceptions of CRF testing of children in primary schools

Currently, there is a significant amount of controversy about the use of fitness tests in schools across the world and within England. On one hand, there are many public health organisations and academics who promote the use of fitness tests within schools (Cohen, Voss & Sandercock, 2015; Lang et al., 2018a). Arguments for fitness testing include how it provides important surveillance information on fitness levels (Cooper et al., 2010; Ferguson, Keating, Bridges, Guan & Chen, 2007). These reasons were strengthened by the findings in Studies 1 to 4 within this thesis. On the other hand, researchers warn about the misuse, lack of validity, and harm fitness testing in schools causes children (Armstrong & Welsman, 2019; Harris & Cale, 2007). The current study found that, overall, teachers had positive perceptions and were in favour of fitness testing in primary schools.

Teachers were able to describe numerous advantages and reasons for fitness testing, including goal-setting, raising awareness of fitness levels, completing a physical challenge, improving children's confidence, a motivation to do more PA, a reference for PA and fitness levels, talent identification and children's enjoyment. These views are similar to those of Heads of PE at secondary schools in England who felt that fitness testing helped promote fitness and PA, promoted pupils' understanding and knowledge of fitness and PA and motivated or assisted with goal-setting (Cale, Harris & Chen, 2014).

This shows that teachers in the different tiers of education (primary and secondary) in England are in favour of children doing fitness tests. A primary objective for fitness testing in schools previously has been reported as promoting pupils' involvement in PA and maintaining fitness for health and well-being (Corbin et al., 1990; Fox & Biddle, 1988). This was not the most frequently cited objective of fitness testing in the opinions of the teachers interviewed in the present study, with just over half of the teachers interviewed (n = 4) stating fitness testing could be used as a motivational tool to do more PA. Using fitness testing for goal-setting was the most frequently cited in the current study, a finding supported by Miller et al. (2016), who investigated teachers' perceptions of the FITNESSGRAM in the US.

A logical reason for implementing fitness tests in schools is so that the results can be used to develop personalised PA programmes and allow them to track and evaluate their progress over time (Keating & Silverman, 2004). However, the results of the current study found that the main use of data from fitness testing was talent identification for school events such as cross-country (n = 4). Only one teacher commented that they use the results to identify children with poor levels of fitness and provided additional opportunities for them to do more PA to improve their CRF. This finding does raise concerns on whether the majority of teachers have sufficient knowledge and training on how to use the results from fitness testing appropriately. Silverman, Keating and Phillips (2010) have previously recommended that fitness testing and fitness education should be a part of a year-long curriculum. Although using the results for talent identification is justifiable, teachers may need additional training on how to embed fitness testing and fitness education as a component of their wider curriculum. However, considering that Heads of PE in secondary schools have reported a lack of guidance and professional development, as well as alarming uses of fitness testing (Cale, Harris & Chen, 2014), opportunities need to be provided for both primary and secondary school teachers on how to embed fitness education, as well as fitness testing into their PE curriculums. A common argument against fitness testing in schools has been that children have negative experiences (Cale & Harris, 2009), and this may actually hinder PA instead of promoting it (Gard & Pluim, 2017). However, a recent study by Simonton, Mercier and Garn (2019) found that there were limited associations between children's experiences of fitness tests with future attitudes and emotions towards PE. The reasons why children have reported that they did not enjoy fitness testing in the past include the following; it does not seem important to them, they do not enjoy the way it is administered and it is not fun (Flohr & Williams, 1997; Fox & Biddle, 1988; Keating, Silverman & Kulinna, 2002). Teachers in the current study also also believed that some children might not enjoy participating in fitness tests. However, the teachers described that, in their experience, children for the most part enjoyed taking part in fitness testing (n = 4). Graser et al. (2011) described that for fitness testing to be a positive and educationally informative experience, pupils would need do the following; feel like they are in a safe environment for testing, understand the purpose of the testing, be able to make connections between their own healthy-fitness levels and their PA behaviours, and conclude the fitness test feeling positive about the experience. Previous researchers have suggested that student self-testing is a way to achieve this (Pangrazi, 2001; Corbin, Pangrazi & Welk, 1995). However, the accuracy of the reported results from self-administered fitness tests could be questioned when administered to primary school children. A method suggested by the teachers in the current study to reduce the likelihood of children not enjoying fitness testing was to do the fitness test grouped by ability. This could prevent children becoming disheartened or demotivated, as they would be participating in the test against peers of a similar fitness level. This would only be possible however if fitness testing was routine.

In 2010, the then outgoing Chief Medical Officer (CMO) for England stated that *"the introduction of a standardised school-based fitness assessment in England may have multiple benefits that extend beyond the benefits of the individual"* (Department of Health, 2010). As previously described in this thesis, there are countries such as Slovenia and states in the US that have adopted mandatory fitness testing for all children. In the current study, the majority of teachers reported that they were in favour of mandatory fitness testing in schools. A study conducted in West Virginia in the US, where the FITNESSGRAM is compulsory, found that PE teachers continue to find value in fitness testing, and for the most part, are following the recommendations from the research related to the appropriate application of the results (Miller et al., 2016). The findings from the current study and Miller et al. (2016) suggest that teachers in England would support national implementation of fitness testing and continue to find value in the process if it was adopted.

8.4.2 Feedback on MPBC

The next part of this chapter discusses the feedback received from teachers specifically on the MPBC project. The data provided from this section of the interviews provides some insight into the motivators for teachers wanting their schools to participate in the MPBC, what their experience of the MPBC was, and finally, what recommendations they had for the future.

The reasons for participating in the MPBC differed between schools depending on whether they already administered fitness testing in some form. Teachers at schools that were already administering fitness testing before the MPBC were more interested in being able to compare how their pupils' fitness compared to those of other schools in the area (n = 4), whereas schools that had not done fitness testing before wanted to gain an understanding of their own pupils' fitness (n = 3). Most teachers (n = 6) that were interviewed described that overall, the MPBC had been a positive experience. However, the specific reasons for these experiences varied. Furthermore, two teachers said that the experience varied between sessions, mainly due to the number of staff from Premier Education that were present at the session and their organisation. Interestingly, following on from the previous section of the discussion about whether or not children enjoy fitness testing (Cale & Harris, 2009), the teachers described how children enjoyed participating in the MPBC. This may be due to the MPBC protocol focusing on personal achievement with each child aiming to improve on their own previous score instead of paying attention to other children in their class. This is highlighted as a critical step to implementing fitness testing in schools (Sachek & Amin, 2018).

Most of the teachers struggled to come up with ways to improve the MPBC. However, one recommendation requested by two different teachers was that they would like more components of physical fitness tested. A physical fitness test battery, such as ALPHA-fit (Ruiz et al., 2011b) or Eurofit (Council of Europe, 1988), were considered for the MPBC. However, to complete a fitness test battery would require additional PE lessons. Many of the tests for other physical fitness components in these fitness batteries require testing one participant at a time. To address this, additional staff would be needed to prevent children from becoming demotivated or bored whilst waiting to be tested. Therefore, the MPBC focused on solely measuring CRF as it is the component of physical fitness that has been most strongly associated with health outcomes (Ruiz et al., 2009), and is a test that allows the measurement of larger groups simultaneously. However, there are methods which may help to overcome this limitation, such as having two children independently record the score of their peer and using the mean result. Another suggestion from teachers on how the MPBC could be improved is if children were grouped by ability when doing the 20mMSR. This was also reported by teachers when asked how issues with fitness testing could be minimised. The teachers described how this would decrease the amount of time it took for the 20mMSR to be completed, cut the amount of time children were waiting for their classmates to finish and reduce the likelihood of children who ran fewer shuttles becoming disheartened with their performance.

8.4.3 Strengths & Limitations

One of the major strengths of this study is its originality, as this is one of only two studies to interview educators about fitness testing in primary schools in England, the previous study being conducted by Harris and Cale (2007). Another strength is the use of pen profiles, as they provided a ‘reader friendly’ method of presenting a quantitatively based analysis procedure. This prevents the data and emergent themes being skewed by certain participants whose views, and opinions, may have been in the minority. Finally, detailed feedback on the MPBC from teachers in the recruited schools was collected, which will help improve the MPBC in the future.

There are several limitations that need to be noted. Firstly, whilst data saturation was reached using the approach devised by Guest, Namey and Chen (2020), the sample size was relatively small, with only seven teachers agreeing to take part in the interviews from the 17 schools that took part in the project. Further, there is the potential for bias, with teachers who agreed to take part in the interviews possibly already having a positive attitude towards fitness testing. Another limitation was that the teachers included in the current study all taught at primary schools in London and their views cannot be generalised to secondary school teachers or teachers from other areas of England. Finally, two of the teachers were not present during all three years of the project. One of the teachers interviewed only joined the school at the end of the second year, whilst another teacher had a sabbatical during the second year, limiting the feedback they could provide on the MPBC.

8.5 Conclusions

The results of this study can enrich our understanding of teachers' perceptions of fitness testing in primary schools in general and provide valuable feedback on the MPBC project. This study found that teachers, overall, have positive perceptions of fitness testing in primary schools and believe that children enjoy participating in fitness tests. Furthermore, education and resources for how the results of fitness testing could be utilised by teachers are needed, as currently most teachers only use fitness test results for talent identification and not as an educational component of PE programmes. The feedback from teachers on the MPBC was positive overall, with teachers reporting that children enjoyed participating in the project. Suggestions for future projects included a physical fitness test battery and grouping children by ability. The results of this study will be used to consider the strengths and limitations of the project overall and make future research recommendations.

Key Findings in Relation to Thesis

Study 1:

- The literature search performed in Study 1 highlighted that numerous studies do not measure CRF post-intervention. As highlighted in the literature review, CRF is an important health outcome that modifying PA behaviour aims to improve and should therefore be a routine measure post-intervention.
- The inclusion of measurements of CRF in studies of PA interventions in children is key to the evaluation of their impact. This study has demonstrated that inclusion of such outcomes facilitates the quantitative synthesis of effects to best understand the impact of PA interventions.
- Further, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that have utilised CRF testing as an outcome, the current study was able to examine this hypothesis.
- The lack of association between improvements in CRF with changes in executive function and academic performance therefore warrant no further research in this thesis.

Study 2:

- Study 2 found that it was difficult to draw comparisons with other studies that had measured CRF in England, with datasets limited to certain regions and non-existent in others. Further, the reporting methods in which the studies reported their findings varied, making it more difficult to draw comparisons between groups and regions. Therefore, England would benefit from adopting a standardised procedure to enable these comparisons to be made.
- Study 2 also demonstrated how feasible it would be to put in place the same CRF testing procedure in a different country and how the results could provide an insight into the CRF levels of children in each country.

Study 3:

- The findings in Study 3 suggest that the sole use of BMI to monitor children's health status may be limited, and that a substantial proportion of children who were categorised as having a healthy weight may actually be at an increased risk of CMD based upon their CRF levels.
- This strengthens the case for CRF testing in schools in England as this would enable public health interventions to better identify and target those at risk.

Study 4:

- The findings in Study 4 provide further evidence of the benefits of regular monitoring of CRF levels in primary schools in England by tracking the CRF levels of the same children over a 3-year period. Study 4 found that children's normative 20mMSR scores were increased with age and that SES had an impact on CRF levels.
- Study 4 demonstrates that if CRF testing was a regular procedure in schools, the data could be used as an evidence base to identify children, schools, or groups (e.g. sex or SES group) that would benefit from additional PA opportunities.

Study 5:

- The opinions of teachers about whether CRF testing should be implemented in primary schools is a key consideration. Study 5 found that teachers had overall positive views regarding fitness testing in primary schools and that most children enjoyed participating in the fitness test.
- Additionally, consideration needs to be made on how to educate teachers on the uses of the data from CRF testing. The findings from Study 5 revealed that those teachers that already administer some form of fitness testing used their results solely for talent identification and not for educational components of their PE programmes.

CHAPTER 9.0 GENERAL DISCUSSION

The overarching aim of this thesis was to determine whether there was a case for cardiorespiratory fitness (CRF) testing, measured using the 20m Multistage Shuttle Run (20mMSR), of children in primary schools in England. This overarching aim was achieved through a number of studies, each with specific objectives and findings. The current chapter will synthesise this research, considering the findings of each of the studies, and their implications as a whole. This will be followed by an overview of the strengths and limitations, future directions for practice and research, and final conclusions.

9.1 Summary of findings

The literature review (Thesis Chapter 2.0) highlighted how CRF levels are associated with a number of physical and mental health outcomes in childhood and adolescence, including obesity (Lang et al., 2018c), cardiometabolic risk (CMR; Mintjens et al., 2018), psychological well-being (Rodriguez-Ayllon et al., 2018), self-efficacy and enjoyment (Barnett et al., 2011). The literature review (Thesis Chapter 2.0) also showed the advantages of using CRF as a surveillance indicator of health instead of, or in addition to, physical activity (PA), with PA having higher intra-individual variability and a weaker association with health (Hurtig-Wennlöf et al., 2007; Rizzo et al., 2007). Furthermore, the literature review (Thesis Chapter 2.0) provided several ways in which CRF testing of children in primary schools could be used, including identifying children who may be at an increased risk of cardiometabolic disease (CMD), tracking changes in CRF over time and how these changes may vary between groups such as socio-economic status (SES), and cohort comparisons between regions and with other countries. These potential applications of data from CRF testing formed the objectives for Study 2 (Thesis Chapter 5.0), Study 3 (Thesis Chapter 6.0) and Study 4 (Thesis Chapter 7.0). The literature review (Thesis Chapter 2.0) also highlighted a gap in previous systematic reviews and meta-analyses (Álvarez-Bueno et al., 2017a; Álvarez-Bueno et al., 2017b; de Greeff et al., 2018; Álvarez-Bueno et al., 2020) on the relationship of CRF and PA with academic performance and executive function which had not investigated how changes in CRF, as a result of a PA intervention, impacted executive function and academic performance in children and adolescents. This led to the systematic review, meta-analysis, and meta-regression being carried out in Study 1 (Thesis Chapter 4.0). The results of the meta-analysis found that PA interventions resulted in small improvements in CRF, which is in line with previous findings (Pozuelo-Carrascosa et al., 2018). However, the PA interventions did not have a significant effect on academic performance or executive function. Additionally, the meta-regression revealed that changes in CRF were not associated with changes in either academic performance or executive function. This finding dissuaded the thesis author from examining the potential link between CRF and academic performance further. Yet, though many have assumed that CRF might moderate the effects of PA upon executive function and academic performance as a result of primarily observational data, through the use of studies that had utilised CRF testing as an outcome the thesis author was able to examine this hypothesis.

Study 2 (Thesis Chapter 5.0) investigated how CRF testing could be used to compare different cohorts between different regions nationally and internationally. By comparing a cross-sectional dataset from the My Personal Best Challenge (MPBC) with data from studies in other regions in England, the thesis author hoped to examine how CRF levels vary among youth across the country. However, data was restricted to certain regions and non-existent in others. The 20mMSR was the CRF test adopted by all large-scale studies in England (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015; Sandercock et al., 2012; Weston, Pasecinic & Basterfield, 2019), however, the protocol varied. Furthermore, the method in which the studies reported the results made it more difficult to draw comparisons between groups and regions (Boddy et al., 2012a; Sandercock, Ogunleye & Voss, 2015; Sandercock et al., 2012; Weston, Pasecinic & Basterfield, 2019). Therefore, England would benefit from adopting a standardised reporting procedure to enable comparisons nationally. Premier Education also began expanding their business and now implement their programmes in the US. This provided the opportunity to investigate how feasible it was to put in place the same CRF testing programme in the US. The CRF testing in the US demonstrated how the MPBC programme could be implemented in two countries and their results compared, providing us an insight into the CRF levels of children in each country.

As reported in the thesis literature review, there are numerous health risks associated with having a low level of CRF, including an increased risk of CMD (Ruiz et al., 2016; Ortega et al., 2008a). However, body mass index (BMI) is currently the only national measure of children's health status in England (National Health Service (NHS), 2019). The aim of Study 3 (Thesis Chapter 6.0) was to perform another cross-sectional analysis from the MPBC dataset to examine the relationship between BMI and CRF and to identify the proportions of children who were at an increased risk of CMD when calculated by these two measures. A previously validated 20mMSR cut-point that was developed by Boddy et al. (2012b) with British children in a similar age-group was applied to the MPBC dataset. The findings of Study 3 (Thesis Chapter 6.0) suggest that the sole use of BMI to monitor children's health status may be limited, as the addition of CRF testing showed that there were proportions of children who were “fat-but-fit” and “lean-but-unfit”. The “lean-but-unfit” group would not be identified if BMI was the only measure used. This strengthens the case for CRF testing in schools in England as this would enable public health interventions to better identify and target those at risk.

The next step after performing the cross-sectional analyses in Study 2 (Thesis Chapter 5.0) and Study 3 (Thesis Chapter 6.0), was to perform a longitudinal analysis to investigate how children’s CRF testing can be utilised to monitor children’s CRF levels during the final years of primary school. This was the largest study in England to explore CRF of the same children longitudinally. Study 4 (Thesis Chapter 7.0) found that boys typically have greater raw 20mMSR performance (no. of shuttles) than girls, but when 20mMSR was normalised to z-scores, sex had no effect. The linear mixed models also found that children’s 20mMSR performance, when reported as no. of shuttles and z-scores, increased with age. Furthermore, children from more deprived schools had lower CRF levels, corroborating with findings in previous studies (Jiménez-Pavón et al., 2010; O’Keeffe et al., 2020). However, this finding was more prominent for younger children, suggesting that younger children attending primary schools where high proportions of children receive the Pupil Premium (PP) may benefit from additional availability of PA opportunities. However, by the end of primary school, children from groups with both high and low SES had similar CRF levels. This study adds further evidence for CRF surveillance in England to help monitor children’s health status and identify groups who would benefit from signposting to health interventions.

During Key Stage 2, where children are aged 7-11 years old, a programme of study for physical education (PE) in the National Curriculum states that children should be taught to compare their performances with previous ones and demonstrate improvement to achieve a personal best (Department of Education, 2013). This programme of study could therefore include monitoring of CRF measured through a fitness test. However, it was important to consider the perceptions of teachers on whether CRF testing should be implemented in primary schools. In Study 5 (Thesis Chapter 8.0), the semi-structured interviews revealed that overall, teachers had positive perceptions regarding fitness testing in primary schools and believed that the majority of children enjoyed participating in fitness tests. This finding demonstrated that teachers in primary schools, as well as secondary schools (Cale, Harris & Chen, 2014), are in favour of implementing fitness tests. However, further consideration does need to be made on how to educate teachers on the uses of CRF testing data. The findings from the interviews showed that the majority of teachers who currently administer fitness tests to their pupils use the results solely for talent identification for events such as cross-country and not as educational components of their PE programmes.

9.2 Implications of Findings

Vital risk factors that predict future non-communicable diseases (NCDs) begin in childhood, and is therefore an important time to begin NCD prevention (Berenson et al., 1998). Recent research has shown discouraging trends for many health-related behaviours and outcomes, including PA (Ekelund, Tomkinson & Armstrong, 2011; Dollman, Norton & Norton, 2005), sedentary behaviours (Nelson et al., 2006), strength (Tremblay et al., 2010) and CRF levels (Tomkinson et al., 2019b). There have been several initiatives released by the UK government in recent years to try and tackle the issues facing children's health, including physical inactivity and obesity (Department of Health & Social Care, 2016; Department of Culture, Media & Sport, 2015; Sport England, 2016). However, sustainable population health surveillance systems to help monitor and quantify risk of future NCDs are needed to effectively implement these strategies (Alwan et al., 2010). Indeed, the former Chief Medical Officer (CMO) for England recently released a report focusing on how more needs to be done to solve childhood obesity (Davies, 2019).

9.2.1 Surveillance Measures of Children's Health in England

Currently, England relies upon measurements of BMI (NHS, 2019) and self-reported PA (Sport England, 2019) to monitor the health of the nation's children. However, self-report questionnaires can be limited by recall bias and social desirability in youth populations (Welk, Corbin & Dale, 2000; Shephard, 2003), and they have a poor ability to identify and understand different PA intensities (Crossley et al., 2019). A recent systematic review highlighted how there were no PA questionnaires for children and adolescents that had both acceptable validity and reliability, and this was partly due to the low methodological quality of the included studies (Hidding et al., 2018). Furthermore, there is no standardised approach to data collection and analysis of children's PA across the UK, with surveillance undertaken separately in England, Wales, Scotland and Northern Ireland (Strain et al., 2018). The use of different surveys makes it difficult to conduct cross-country comparisons (Strain et al., 2018), whereas Study 2 (Thesis Chapter 5.0) demonstrated how this was feasible when using the 20mMSR. It is now technologically feasible to undertake large-scale surveillance of PA using objective measures. Although accelerometers are more reliable in measuring PA than self-report questionnaires (Adamo et al., 2009), there remains a number of limitations. These limitations include variations in: the definition of of thresholds for exercise intensity, frequency of data collection, wear time and their inability to differentiate between different types of movement (Jurak et al., 2020). However, in relation to the current PA guidelines (Department of Health & Social Care, 2019), it is worth noting the issue on the appropriateness of using devices to measure compliance with recommendations that have been derived from data based on self-reported PA. This issue was highlighted by Trioano et al. (2014), who stated that the evaluation of the adherence to PA guidelines based on accelerometer outcomes is inappropriate because the behavioural metrics used to develop the guidelines differ conceptually from accelerometer-based measures of moderate-to-vigorous PA (MVPA). Due to the limitations of PA as a surveillance measure, Jurak et al. (2020) described how measuring the long-term response to PA, CRF, can provide a more stable factor in assessing health risks. Study 3 (Thesis Chapter 6.0) highlighted how this could be achieved using the 20mMSR and used as a screening tool for children with an increased risk of CMD.

9.2.2 Cardiorespiratory Fitness Testing as a Surveillance Measure

The findings of this thesis have a number of important implications for policymakers and researchers in relation to whether there is a case for CRF testing to be utilised in primary schools to aid the surveillance of children's health alongside current measures. Hall et al. (2012) described how population health surveillance provides a basis to: 1) guide policy and intervention efforts by identifying populations at greater risk; and 2) evaluate and monitor the progress and impact of policies and interventions. Therefore, the next section of this chapter will discuss how the findings of this thesis relate to the two points described by Hall et al. (2012).

9.2.2.1 Cardiorespiratory Fitness Testing to Guide Policy and Intervention Efforts by Identifying Populations at Greater Risk

Surveillance measures are crucial to guide policy efforts in identifying which parts of a population are at greater risk (Hall et al., 2012). Evidence from tracking studies suggests that a low level of CRF in youth is associated with all-cause mortality in adulthood (Högström, Norströ & Nordström, 2016; Sato et al., 2009). The findings of Study 2 (Thesis Chapter 5.0), Study 3 (Thesis Chapter 6.0) and Study 4 (Thesis Chapter 7.0) in this thesis all provided examples of how CRF measurement could be utilised to identify those at greater risk, including between populations in different regions, as well as children in different socio-economic and weight status groups. These findings provide policymakers an insight into the geographical areas and groups of children that are most in need of PA interventions. Further, these findings add support to previous calls for the measurement and surveillance of CRF to be adopted by clinicians, governments and PE teachers to help identify those in most need of lifestyle interventions (Ruiz et al., 2016; Tomkinson et al., 2017; Lang et al., 2018a). However, CRF testing is rarely used by schools, clinicians or governments to identify children with poor health profiles or provide feedback to children and their parents/guardians. One possible explaination for this is the availability of national and international standards of BMI, such as the National Child Measurement Programme (NCMP) in England (NHS, 2019), with it being the only objective national measure used to monitor children's health status. The findings of Study 3 (Thesis Chapter 6.0) demonstrated why measuring CRF should be implemented alongside BMI as a surveillance health indicator, with significant proportions of children categorised as "lean-but-unfit" and "fat-but-fit". However, if CRF is not adopted as a national surveillance indicator alongside BMI, the findings of Study 2 (Thesis Chapter 5.0) highlighted the need for a central, publicly available repository for data on children's CRF. This would allow schools, researchers and government to deposit, store and access data on children's CRF from across England and the rest of the UK.

9.2.2.2 Cardiorespiratory Fitness Testing to Evaluate and Monitor the Progress and Impact of Policies and Interventions

Monitoring involves the systematic collection, analysis and interpretation of data from well-defined populations (Hallal et al., 2012b). Domone et al. (2016) had previously emphasised that large-scale fitness testing needs to be conducted within field settings instead of laboratory settings and identified the 20mMSR as the most scalable of valid and reliable field fitness tests. Study 4 (Thesis Chapter 7.0) demonstrated the feasibility of monitoring CRF using the 20mMSR and it could be used in the future to monitor and evaluate the impact of policies and interventions that are implemented.

Study 1 (Thesis Chapter 4.0) demonstrated how CRF testing can be used to evaluate PA interventions regardless of whether improving CRF was the primary outcome of the original study. For example, although Study 1 (Thesis Chapter 4.0) found no significant effect of changes in CRF upon executive function or academic performance, the PA interventions did result in a significant improvement in CRF. This would be an important finding in any PA intervention study due to the health benefits associated with improved CRF (Ortega et al., 2008a). However, the literature search conducted in Study 1 (Thesis Chapter 4.0) indicated that many research studies only measured CRF at baseline (Chaddock et al., 2012; Howie, Schatz & Pate, 2015). It is also important to note that there is a lack of evidence of the effect PA interventions have on total PA levels (Jones et al., 2019). This brings into question whether total PA should be used as a baseline and post-intervention measure to evaluate the effectiveness of PA interventions. This also raises further uncertainty on whether measures of PA should be used to evaluate national policies focused on children's PA. Therefore, the findings of Study 1 (Thesis Chapter 4.0), coupled with the questions over using PA measurement as a pre- and post-intervention measurement, indicate that the routine measurement of CRF may be used to evaluate the effectiveness of national policies, and should be measured at post-intervention as well as baseline in future intervention studies.

9.3 Strengths and Limitations

The novelty of this thesis is that it has implemented a CRF testing programme with the same participants over a 3-year period. This was only possible through the partnership with Premier Education which then allowed the involvement of their staff and resources. This is the largest cohort of primary school children in England to have their CRF tracked over an extended period of time. The results are shown in Study 4 (Thesis Chapter 7.0), but provided the foundation for Study 2 (Thesis Chapter 5.0) and Study 3 (Thesis Chapter 6.0) to be completed. Previous large-scale studies in England, that have tested the CRF of children, have used a repeated cross-sectional design (Sandercock, Ogunleye & Voss, 2015; Boddy et al., 2012a), and involved researchers carrying out the testing in schools or transporting children to laboratory or field-testing facilities, which is often done outside the curriculum. This can often encounter considerable costs and logistical challenges, such as transport costs, which make the testing protocols less scalable than the method applied in the MPBC programme.

Another major strength of this thesis was how different research questions have been answered to consider the case for CRF testing in primary schools in England from a variety of dimensions. These have included: examining the relationship between CRF with academic performance, executive function, and BMI; identifying proportions of children at greater risk to poor health as indicated by their CRF; providing evidence on how CRF levels of different groups of children change over time; providing examples on how CRF testing can be utilised to evaluate programmes and interventions in schools, as well as in cohort comparisons; and analysing qualitative data on the primary school teachers' perceptions of fitness testing. By attempting to answer this broader range of research questions involving fitness testing in schools, this thesis has been able to make more informed conclusions. Moreover, this thesis also encompassed a range of different analytical techniques, including a meta-analysis and meta-regression (Study 1, Thesis Chapter 4.0), linear mixed modelling (Study 4, Thesis Chapter 7.0), and thematic analysis (Study 5, Thesis Chapter 8.0).

Nevertheless, there are several limitations within the thesis that need to be acknowledged. Firstly, one variable that limited the generalisability of the findings of Study 3 (Thesis Chapter 6.0) and Study 4 (Thesis Chapter 7.0) was the localised area of data collection in the London boroughs of Camden and Islington. This was also a limitation for Study 2 (Thesis Chapter 5.0) where data collection in the US was limited to inner-city elementary schools in Birmingham, Alabama, and Oakland, California. Therefore, the level of localised data in these studies may not represent the CRF of children in other parts of England and the US, such as in rural areas. However, Sandercock, Ogunleye and Voss (2011) found no significant differences in CRF levels between rural and urban children in England. Furthermore, this limitation applies to the findings in Study 5 (Thesis Chapter 8.0) as the teachers who participated in the interviews were all staff from the schools that took part in the MPBC. These findings may under-represent the ideologies of teachers about fitness testing in schools from other locations, socio-economic groups, and ethnic minorities. A second limitation in this thesis was that PA levels were not assessed. This limits the ability to infer the causes of findings such as those made in Study 4 (Thesis Chapter 7.0) as it was unable to determine if changes in CRF are being mediated by changing PA levels, which is something inferred from the examination of interventions introduced in schools in the systematic review and meta-analysis performed in Study 1 (Thesis Chapter 4.0). A third limitation in this thesis was that the only component of physical fitness measured was CRF. This was due to two reasons. Firstly, to conduct a fitness test battery such as the ALPHA-fit (Ruiz et al., 2011b) or Eurofit (Council of Europe, 1988) test batteries would require additional PE lessons. Secondly, many of the tests in these lessons require one participant being tested at a time. This would have required additional staff to prevent the children who were not being tested from becoming de-motivated or bored. Therefore, CRF was the sole component of physical fitness measured as it has the strongest association with health outcomes (Ruiz et al., 2009), and allowed large groups to be tested simultaneously. A fourth limitation was that several participant demographics were not collected fully or not collected at all. Several schools (n = 5) did not provide their pupils' date of birth, and only provided the academic year of each pupil. For children with no date of birth provided, a date of birth halfway through the academic year (01/03/**) was used, this meant that there could be up to a 6-month error in a child's age. As part of the data collection process schools were asked to provide details on whether each child had special educational needs, spoke English as an additional language, or received the PP. However, a number of schools were not willing to provide this information, so these variables were not included as covariates in any of the analyses performed in the studies. Due to the limited number of participants that had provided individual data on whether they received the PP a school-level measure was used. This school-level measure reports the percentage of children who are entitled to the PP from all children who are enrolled at the school, not just the children in academic Years 4 to 6. A fifth limitation is that the time of day and location (inside or outside) were not controlled. The time of day was not controlled due to the MPBC taking place during curricular PE lessons and the timetables for PE varied between schools. The location of the testing within the school was not controlled for either, as the facilities available at the schools varied, such as the size of the hall or playground, as well as the weather conditions.

9.4 Future Directions

In addition to the novel findings presented in this thesis, there a number of proposed recommendations for future practice and research.

9.4.1 Recommendations for practice

- The MPBC should be rolled out to all schools that Premier Education are currently working with. As Premier Education are currently working in more than 3,000 primary schools across the country this would provide a nationally representative dataset for the CRF levels of children in England.
- The MPBC should incorporate additional tests for physical fitness in schools that want to get a more rounded representation of their pupils' fitness.
- All PE teaching staff, whether school staff or from an external company such as Premier Education, who want to conduct fitness testing need to receive training on how to administer the test appropriately to avoid any children having negative experiences.
- PE teachers, whether they are school staff or from an external company such as Premier Education, need to be provided with resources and educated on how to incorporate fitness testing as a part of a wider fitness education component of their curriculum. Further training needs to be provided on how to use the results from

CRF testing in the planning of future extra-curricular activities and PE programmes. The results need to be used to identify children who would benefit from additional PA, as well as talent identification.

- Fitness testing in schools needs to be focused on children's personal achievement and improvement. Strategies for goal-setting should also be applied.
- To avoid de-motivation and minimise risk of embarrassment or bullying, children should be grouped by ability before testing.
- The NCMP should consider adopting the 20mMSR as an additional measure to BMI to monitor and track the health status of children.
- Additional information that may confound the relationship between any intervention and CRF needs to be collected to enable causal estimation of intervention effects from large observational datasets.

9.4.2 Recommendations for future research

- Future studies that collect data on CRF of children need to ensure standardised reporting procedures are followed so that comparisons between datasets can be made.
- Longitudinal studies are needed to track CRF levels from children making the transition from primary school to secondary school.
- Researchers should use comprehensive formative research to incorporate the opinions of children on how they feel about participating in fitness tests.
- PA interventions need to use the 20mMSR as an evaluative tool after the intervention, as well as at baseline. This would provide an additional feedback measure to researchers on the effect of their intervention as well as provide the

children with comprehensible feedback about whether the intervention had made them fitter.

- Findings from Study 4 (Thesis Chapter 7.0) suggest that younger children who attend schools that have a higher proportion of children entitled to the PP may benefit from additional PA opportunities.
- Primary school teachers believed that children enjoyed taking part in the fitness test as a part of the MPBC programme (Study 5, Thesis Chapter 8.0). However, future studies into the perceptions and attitudes of primary school children and their parents on fitness testing are needed to determine whether the perceptions of their teachers are true.

9.5 Conclusions

Overall, this body of work has considered the case for whether CRF testing of children should be implemented in primary schools in England and concluded that there is indeed evidence to suggest it can provide a number of benefits. This thesis has demonstrated that CRF testing in schools can be used as a tool to evaluate PA interventions, identify children that are at an increased risk to CMD, track CRF over time and how changes in CRF may differ between groups, and make cohort comparisons within and between countries. Furthermore, this thesis has shown that teachers' perceptions of fitness testing are positive, and that they believe children enjoy participating.

This thesis has expanded on the current evidence base of children's CRF testing and demonstrated a scalable method that could be implemented on a large scale across England. By making the MPBC an initiative used in all schools in which Premier Education are employed, it could provide a foundation for a nationally representative cohort of children's fitness data in England. This could be used to monitor whether the PA initiatives put forward by Sport England and the UK government as well as more localised programmes are having a positive effect on CRF. Additionally, Premier Education should use a physical fitness test battery in schools that are willing, as this would provide data on the other components of physical fitness. Future studies that report CRF of children in England need to ensure they report the descriptive data for the number of shuttles completed, end speed, relative peak $\dot{V}O_2$ ($\dot{V}O_{2peak}$), and z-scores so that comparisons can be made easily between different regions in England. This thesis has focused on the CRF of children in primary school, however future longitudinal studies should also track the CRF of children into adolescence in secondary school where the PA of children has been found to decrease (Brodersen et al., 2007). Additionally, educational materials need to be provided to staff who deliver PE, whether internal school staff or from an external company, on how the results from the CRF tests could be used in the planning of their PE programmes to try and improve the CRF of their students.

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CHAPTER 12.0 APPENDICES

Appendix I: P60795 Information Sheets and Consent Forms

P60795 Headteacher Information Sheet

Dear [INSERT NAME OF HEAD TEACHER]

R.E. Measurement of children's fitness levels, BMI, and academic performance – Year 4 - 6

Thank you for considering taking part in this innovative and unique research project.
The data collected and conclusions drawn will influence the future monitoring of children's health and wellbeing in this country.

In 2010 the outgoing Chief Medical Officer stated that "The introduction of a standardised school based fitness assessment in England may have multiple benefits that extend beyond the benefits for the individual". This was in response to the fact that children's fitness levels have been decreasing 7-9% every decade. It was further suggested that increasing the physical activity levels of children would contribute to the following:

- Lowering the lifetime risk of disease.
- Building a lifelong habit of participation in physical activity.
- Higher educational attainment.
- Maintaining a healthy weight.
- Improving social and mental wellbeing.

It is proposed by the Chief Medical Officer that by formalising a fitness assessment within the school environment would increase awareness of physical fitness as an area of health importance throughout the population. This may provide a stimulus for the cultural change that is so desperately needed.

We would also like to collect data on children's BMI, academic performance (from teachers' reports), and other demographic factors (gender, postcode, date of birth, ethnicity, whether a child has special educational needs, speaks English as an additional language, or received the pupil premium). This would allow us to investigate the relationship cardiorespiratory fitness has with these measures.

It is proposed that members of Premier Sport, who are already delivering [PHYSICAL EDUCATION LESSONS / EXTRA CURRILUAR ACTVITIES] deliver the Multi-Stage Fitness Test (bleep test) and BMI measurements as part of their PE lesson two times per year over the next two years. The collected data will be analysed (anonymously) by researchers from Coventry University. They will track fitness over the next 2 years and investigate fitness' relationship with the other factors measured. Testing will be completed at times agreed with you and the appropriate teacher.

Children's participation is voluntary and they are free to withdraw from the study at any time.

Letters will be sent to parents of the appropriate children offering them the chance to opt into this process. By signing below you consent, on behalf of [INSERT SCHOOL].

Content removed on data protection grounds

P60795 Headteacher Consent Form

Consent Form:
R.E. Measurement of children's fitness levels, BMI, and academic performance – Year 4 - 6

Please initial box

1. I understand that the children's participation is voluntary and that I am free to withdraw my pupils at any time, without giving any reason, without their medical care or legal rights being affected. ☐

2. I understand that anonymised data obtained may be looked at by responsible individuals from the Coventry University or from regulatory authorities where it is relevant to the children's taking part in research. I give permission for these individuals to have access to these records. ☐

I agree to allow the pupils in my school to take part in the above study.

I hereby confirm that I consent for [SCHOOL] take part in the above research investigation:

PRINT NAME:

____

SIGN NAME:

____

DATE:

____

P60795 Parents/Guardians Information Sheet

[ADDRESS 1]
[ADDRESS 2]
[ADDRESS 3]
[ADDRESS 4]

Dear [INSERT NAME]

R.E. Measurement of children's fitness levels, BMI, and academic performance in Year 4 – 6 at [SCHOOL]

[SCHOOL] has recently agreed to take part in a research study with Premier Sport, ukactive, and Coventry University.

This will involve, during two Physical Education lessons spread through the year, pupils taking part in a Multi-Stage Fitness Test. This test involves running 20meter shuttles in time with an automated 'bleep' that increases in speed throughout the exercise. The test finishes when the child decides to stop, or cannot keep up with the 'bleeps'. Children will also have their height and weight measured during this PE lesson so that their BMI can be calculated. Your child's academic performance will also be collected using the reports from their class teacher.

The main aim of the study is to assess the fitness levels of the pupils, and was recommended by the Chief Medical Officer for the United Kingdom in 2010. Knowledge of a child's fitness levels can aid in the analysis of at risk pupils and provide assistance where necessary to increase physical activity levels.

Increasing the physical activity levels of children would contribute to the following:

- Lowering the lifetime risk of disease.
- Building a lifelong habit of participation in physical activity.
- Higher educational attainment.
- Maintaining a healthy weight.
- Improving social and mental wellbeing.

There will be several demographic measures taken including; gender, date of birth, postcode, ethnicity, whether your child has special educational needs, speaks English as additional language, and whether they receive the pupil premium. This study will investigate the influence of these measures on children's fitness. Researchers will not be able to identify individual children as all data shared will be anonymised.

Your child's participation is voluntary and they are free to withdraw from the study at any time.

If you consent for your child to take part in this investigation and for anonymised data to be shared with researchers from Coventry University please complete the form below and return to [INSERT TEACHERS NAME].

Kind regards,

[HEAD TEACHER]

P60795 Parents/Guardians Consent Form

PARENT/GUARDIAN CONSENT FORM:
R.E. Measurement of children's fitness levels, BMI, and academic performance in Year 4 – 6 at [SCHOOL]

I ____ (name of parent/guardian)

Declare that I wish my child _______________________________________

To take part in the investigation detailed above, and do consent for anonymised data collected to be shared with Coventry University.

Signed ____ Date. __________

Appendix II: P68526 Information Sheets and Consent Forms

P68526 Headteacher Information Sheet

Comparison of children's fitness levels and academic performance between the United Kingdom and the United States

HEADTEACHER INFORMATION SHEET

Your school is being invited to take part in research comparing the fitness levels and academic performance of children in the UK and the US. Sam Tuvey, at Coventry University is leading this research. Before you decide to take part, it is important you understand why the research is being conducted and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?
The purpose of the study is to compare the fitness levels of children in the UK and US using the same standardised practices. We will also look at the relationship between academic performance and fitness and see if this differs between the two countries.

Why has my child been chosen to take part?
Your school is invited to participate in this study because Premier Sport are working with children in your school aged 8-11 years old.

What are the benefits of taking part?
By taking part you will be helping Premier Sport and Coventry University to better understand the how the fitness levels compare between children in the UK and the US.

Are there any risks associated with taking part?
This study has been reviewed and approved through Coventry University's formal research ethics procedure. There are no significant risks associated with participation. Children in your school will take part in the 20m Multistage Shuttle Run (also known as the PACER and bleep test). The 20mMSR is an exhaustive protocol i.e. participants will be asked to run until they cannot keep pace with the automated 'bleeps'. This is however a voluntary exercise and participants are free to stop at any point during the test. The risk is mediated by the fact that Premier Sport coaches are experienced in the delivery of such sessions and that fitness tests will be incorporated into wider PE lessons that include fun and widely accessible activities. All coaches will also have first aid qualifications.

Do the children have to take part?
No – it is entirely up to each child and their parents/guardians. If you decide to opt your school in, please keep this Information Sheet and complete the Informed Consent Form to show that you understand your rights in relation to the research, and that you are happy for your school to participate. You are free to withdraw your school's information from the project data set at any time until the data are destroyed on 31/01/2020. You should note that your data may be used in the production of formal research outputs (e.g. journal articles, conference papers, theses and reports) prior to this date and so you are advised to contact the university at the earliest opportunity should you wish to withdraw from the study. To withdraw, please contact the lead researcher (contact details are provided below). Please also contact the Research Support Office email hls.rso@coventry.ac.uk so that your request can be dealt with promptly in the event of the lead researcher's absence. Your school do not need to give a reason. A decision to withdraw, or not to take part, will not affect your school in any way.

What will happen if I decide to let my school take part?
Children in your school will complete the 20m Multistage Shuttle Run during a PE lesson. Their date of birth and gender will also be recorded. Their academic performance will be obtained from the school office.

Data Protection and Confidentiality
The children's data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR) and the Data Protection Act 2018. All information collected about the children will be kept strictly confidential by Premier Sport. It will then be anonymised before being transferred securely via SharePoint to researchers at Coventry University. The data will be referred to by a unique participant number rather than by children's name. The data will only be viewed by Premier Sport and the research team at Coventry University. All electronic data will be stored on a password-protected computer file at Premier Sport and Coventry University. All paper records will be stored in a locked filing cabinet at Premier Sport. The lead researcher will take responsibility for data destruction and all collected data will be destroyed on or before 31/01/2020.

Data Protection Rights
Coventry University is a Data Controller for the information you provide. You have the right to access information held about you. Your right of access can be exercised in accordance with the General Data Protection Regulation and the Data Protection Act 2018. You also have other rights including rights of correction, erasure, objection, and data portability. For more details, including the right to lodge a complaint with the Information Commissioner's Office, please visit www.ico.org.uk. Questions, comments and requests about your personal data can also be sent to the University Data Protection Officer - enquiry.ipu@coventry.ac.uk

What will happen with the results of this study?
The results of this study may be summarised in published articles, reports and presentations. Key findings will always be made anonymous in any formal outputs unless we have your prior and explicit written permission to attribute them to you by name.

Making a Complaint
Content removed on data protection grounds

P68526 Headteacher Consent Form

UK active — More people More active More often | Coventry University | Premier Sport.org

HEADTEACHER INFORMED CONSENT FORM:

Comparison of children's fitness levels and academic performance between the United Kingdom and the United States

Your school is invited to take part in this research study for the purpose of collecting data on the fitness levels and academic performance of children in the UK and the US.

Before you decide to take part, you must **read the accompanying Headteacher Information Sheet**.

Please do not hesitate to ask questions if anything is unclear or if you would like more information about any aspect of this research. It is important that you feel able to take the necessary time to decide whether or not you wish to take part.

If you are happy for your school to participate, please confirm your consent by circling YES against each of the below statements and then signing and dating the form as Headteacher.

1	**I confirm that I have read and understood the Headteacher Information Sheet for the above study and have had the opportunity to ask questions**	**YES**	**NO**
2	**I understand my school's participation is voluntary and that I am free to withdraw my school's data, without giving a reason, by contacting the lead researcher and the Research Support Office at any time until the date specified in the Headteacher Information Sheet**	**YES**	**NO**
3	**I understand that all the information my school provide will be held securely and treated confidentially**	**YES**	**NO**
4	**I am happy for my school's anonymous data to be shared with researchers at Coventry University**	**YES**	**NO**
5	**I am happy for the information my school provides to be used (anonymously) in academic papers and other formal research outputs**	**YES**	**NO**
6	**I agree for my school to take part in the above study**	**YES**	**NO**

Thank you for your participation in this study. Your help is very much appreciated.

School Name	Headteacher's Name	Date	Signature
	Researcher	Date	Signature

P68526 Parents/Guardians Information Sheet

Comparison of children's fitness levels and academic performance between the United Kingdom and the United States

PARTICIPANT INFORMATION SHEET

Your child is being invited to take part in research comparing the fitness levels and academic performance of children in the UK and the US. Sam Tuvey, at Coventry University is leading this research. Before you decide to take part, it is important you understand why the research is being conducted and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?
The purpose of the study is to compare the fitness levels of children in the UK and US using the same standardised practices. We will also look at the relationship between academic performance and fitness and see if this differs between the two countries.

Why has my child been chosen to take part?
Your child is invited to participate in this study because they are attending one of the schools that Premier Sport are working in, and they are aged 8-11 years old.

What are the benefits of taking part?
By consenting for your child to take part, you will be helping Premier Sport and Coventry University to better understand the how the fitness levels compare between children in the UK and the US.

Are there any risks associated with taking part?
This study has been reviewed and approved through Coventry University's formal research ethics procedure. There are no significant risks associated with participation. Your child will take part in the 20m Multistage Shuttle Run (also known as the PACER and bleep test). The 20mMSR is an exhaustive protocol i.e. participants will be asked to run until they cannot keep pace with the automated 'bleeps'. This is however a voluntary exercise and participants are free to stop at any point during the test. The risk is mediated by the fact that Premier Sport coaches are experienced in the delivery of such sessions and that fitness tests will be incorporated into wider PE lessons that include fun and widely accessible activities. All coaches will also have first aid qualifications.

Does my child have to take part?
No – it is entirely up to you and your child. If you or your child do decide to take part, please keep this Information Sheet and complete the Informed Consent Form to show that you understand your rights in relation to the research, and that you are happy for your child to participate. Please note down your participant number (which is on the Consent Form) and provide this to the lead researcher if you seek to withdraw from the study at a later date. You are free to withdraw your child's information from the project data set at any time until the data are destroyed on 31/01/2020. You should note that your child's data may be used in the production of formal research outputs (e.g. journal articles, conference papers, theses and reports) prior to this date and so you are advised to contact the university at the earliest opportunity should you wish to withdraw your child from the study. To withdraw, please contact the lead researcher (contact details are provided below). Please also contact the Research Support Office email hls.rso@coventry.ac.uk so that your request can be dealt with promptly in the event of the lead researcher's absence. You and your child do not need to give a reason. A decision to withdraw, or not to take part, will not affect your child in any way.

What will happen if I decide to let my child take part?
Your child will complete the 20m Multistage Shuttle Run during a PE lesson. Their date of birth and gender will also be recorded. Their academic performance will be obtained from your child's school office.

P68526 Parents/Guardians Consent Form

Participant No.

INFORMED CONSENT FORM:

Comparison of children's fitness levels and academic performance between the United Kingdom and the United States

Your child is invited to take part in this research study for the purpose of collecting data on fitness levels and academic performance.

Before you decide allow your child to take part, you must **read the accompanying Participant Information Sheet.**

Please do not hesitate to ask questions if anything is unclear or if you would like more information about any aspect of this research. It is important that you feel able to take the necessary time to decide whether or not you wish to take part.

If you are happy for your child to participate, please confirm your consent by circling YES against each of the below statements and then signing and dating the form as participant.

1	**I confirm that I have read and understood the Participant's Information Sheet for the above study and have had the opportunity to ask questions**	**YES**	**NO**
2	**I understand my child's participation is voluntary and that I am free to withdraw my child's data, without giving a reason, by contacting the lead researcher and the Research Support Office at any time until the date specified in the Participant's Information Sheet**	**YES**	**NO**
3	**I understand that all the data and information my child provides will be held securely and treated confidentially**	**YES**	**NO**
4	**I am happy for my child's anonymous data to be shared with researchers at Coventry University**	**YES**	**NO**
5	**I am happy for the data and information my child provides to be used (anonymously) in academic papers and other formal research outputs**	**YES**	**NO**
6	**I agree for my child to take part in the above study**	**YES**	**NO**

Thank you for your participation in this study. Your help is very much appreciated.

Participant's Name	Parent/Guardian Name	Date	Signature
	Researcher	Date	Signature

Participant Consent form

Appendix III: P82273 Information Sheet and Consent Form

P82273 Participant Information Sheet

My Personal Best Challenge – Teacher Interviews

PARTICIPANT INFORMATION SHEET

You are being invited to take part in research on children's fitness testing primary schools. Samuel Tuvey, PhD Researcher at Coventry University is leading this research. Before you decide to take part, it is important you understand why the research is being conducted and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?
The purpose of the study is to collect feedback from PE coordinators and headteachers of schools that took part fully or withdrew from the My Personal Best Challenge. We also want to understand your opinions on fitness testing in schools in general, what you believe are factors that can facilitate or create barriers to fitness testing.

Why have I been chosen to take part?
You are invited to participate in this study because you are a PE coordinator / headteacher at a primary school that was invited to take part in the My Personal Best Challenge. The My Personal Best Challenge involved conducting a fitness test with the students at your school in Years 4-6. Your school may have taken part during all 3 years of the study or withdrawn at some point during the study.

What are the benefits of taking part?
By sharing your experiences with us, you will be helping Samuel Tuvey and Coventry University to better understand the following:
1) How to improve the implementation of the My Personal Best Challenge project.
2) The opinions of teachers on fitness testing with children in a primary school setting.
3) Factors that can affect a school's involvement in fitness testing.

Are there any risks associated with taking part?
This study has been reviewed and approved through Coventry University's formal research ethics procedure. There are no significant risks associated with participation.

Do I have to take part?
No – it is entirely up to you. If you do decide to take part, please keep this Information Sheet and complete the Informed Consent Form to show that you understand your rights in relation to the research, and that you are happy to participate. Please note down your participant number (which is on the Consent Form) and provide this to the lead researcher if you seek to withdraw from the study at a later date. You are free to withdraw your information from the project data set at any time until the data are fully anonymised in our records on 30th April 2019. You should note that your data may be used in the production of formal research outputs (e.g. journal articles, conference papers, theses and reports) prior to this date and so you are advised to contact the university at the earliest opportunity should you wish to withdraw from the study. To withdraw, please contact the lead researcher (contact details are provided below). Please also contact the Research Support Office email hls.rso@coventry.ac.uk so that your request can be dealt with promptly in the event of the lead researcher's absence. You do not need to give a reason. A decision to withdraw, or not to take part, will not affect you in any way.

What will happen if I decide to take part?
You will be asked a number of questions regarding the My Personal Best Challenge, your opinions on fitness testing, and what factors within a school may affect the implementation of fitness testing in a school setting. The interviews will take place over the telephone at a time that is convenient to you. Ideally, we would like to audio record your responses (and will require your consent for this), so the location should be in a fairly quiet area. The interview should take around 15-20 minutes to complete.

Data Protection and Confidentiality
Your data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR) and the Data Protection Act 2018. All information collected about you will be kept strictly confidential. Unless they are fully anonymised in our records, your data will be referred to by a unique participant number rather than by name. If you consent to being audio recorded, all recordings will be destroyed once they have been transcribed. Your data will only be viewed by the researcher/research team. All electronic data will be stored on a password-protected computer file at Coventry University. Your consent information will be kept separately from your responses in order to minimise risk in the event of a data breach. The lead researcher will take responsibility for data destruction and all collected data will be destroyed on or before 31/0/2020.

Data Protection Rights
Coventry University is a Data Controller for the information you provide. You have the right to access information held about you. Your right of access can be exercised in accordance with the General Data Protection Regulation and the Data Protection Act 2018. You also have other rights including rights of correction, erasure, objection, and data portability. For more details, including the right to lodge a complaint with the Information Commissioner's Office, please visit www.ico.org.uk. Questions, comments and requests about your personal data can also be sent to the University Data Protection Officer - enquiry.ipu@coventry.ac.uk

What will happen with the results of this study?
The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will always be made anonymous in any formal outputs unless we have your prior and explicit written permission to attribute them to you by name.

Content removed on data protection grounds

P82273 Participant Consent Form

Participant No.

Premier Sport.org Coventry University UK active

INFORMED CONSENT FORM:

My Personal Best Challenge – Teacher Interviews

You are invited to take part in this research study for the purpose of collect feedback from PE coordinators and headteachers of schools that took part fully or withdrew from the My Personal Best Challenge. We also want to understand your opinions on fitness testing in schools in general, what you believe are factors that can facilitate or create barriers to fitness testing.

Before you decide to take part, you must **read the accompanying Participant Information Sheet.**

Please do not hesitate to ask questions if anything is unclear or if you would like more information about any aspect of this research. It is important that you feel able to take the necessary time to decide whether or not you wish to take part.

If you are happy to participate, please confirm your consent by circling YES against each of the below statements and then signing and dating the form as participant.

1	**I confirm that I have read and understood the Participant Information Sheet for the above study and have had the opportunity to ask questions**	**YES**	**NO**
2	**I understand my participation is voluntary and that I am free to withdraw my data, without giving a reason, by contacting the lead researcher and the Research Support Office at any time until the date specified in the Participant Information Sheet**	**YES**	**NO**
3	**I have noted down my participant number (top left of this Consent Form) which may be required by the lead researcher if I wish to withdraw from the study**	**YES**	**NO**
4	**I understand that all the information I provide will be held securely and treated confidentially**	**YES**	**NO**
5	**I am happy for the information I provide to be used (anonymously) in academic papers and other formal research outputs**	**YES**	**NO**
6	**I am happy for the interview to be audio recorded**	**YES**	**NO**
7	**I agree to take part in the above study**	**YES**	**NO**

Thank you for your participation in this study. Your help is very much appreciated.

Participant's Name	Date	Signature
Researcher	**Date**	**Signature**

Appendix IV: MPBC Lesson Plan

Year 4-6 My Personal Best Challenge – Lesson Plan

Equipment required:

- Tall cones, markers, music player, bleep test cd (ipod), trundle wheel, recording literature/resources, tutor questions.

Set Up:

- Using RED markers, mark out a 20 x 20 metre (safety zone) – using WHITE cones mark out 15 start points at one end of the 20 x 20 metre area and BLUE cones adjacent to identify start and end points of the laps

Risk assessments/points to consider:

- Ensure children are prepared physically and mentally for the lesson to avoid injury and illness, set up a safety area and check for slips and trips, all participants should be wearing appropriate footwear e.g. trainers or pumps and must have suitable clothing to perform physical activities e.g. PE kit or track suit

Learning Outcomes – what will the children learn?

- Describe why physical activity is good for health and well-being
- Physical activity helps your bones get stronger. Muscles stronger. Good for heart and lungs.
- Respond safely to tasks performed alone/with others

Activity Objectives – What will the children do?

- Improve: skills of running, jogging.
- Experience: outdoor areas, measuring and timing activities.
- Develop: understanding of safe practice linked to activities.

Introduction Activities

- Welcome and introduce teacher/coach to the group

- Using the class register split children into 2 groups 1-15 on the register and 16-30 and hand out relevant no bibs

Prepare children for next tasks

- Group 1 – children 1-15 will make their way out to perform the PB Challenge
- Group 2 – children 16-30 will remain in the classroom with the designated adult who will take the height and weight measurements of the children and record on relevant record sheet – children then also work out in their groups how much minutes of physical activity they do each week and how much is structured and un-structured?

Preparation Activities – Warm Up

- Children move around the safety zone in different directions with control and avoiding each other.
- On the Coaches command the children move in a range of different ways – e.g. forwards, backwards, sideways, skipping, jumping hopping each time emphasising control.
- Raise intensity for 2 mins and ask children:

Q 1: What is happening to their bodies now they have been doing physical activity?

Q2: Why is this good for us?

- Finish activity by moving the children to the starting position/cones (1-15)

Main Activity

- Select two learners to demonstrate the PB challenge using the demonstration lap on the audio resource.

- NB – if required complete one or two practice laps with the children to ensure everybody is clear on the expectations of the task
- Children turn to the person at the side of them and complete a pair and share activity

Q1: how are you going to ensure you personally performing to your best when completing the challenge – drill down questions to get children to not exert themselves to early at the start, pace themselves.

Q2: What will help you perform to your best - drill down team work, encouragement advice – team ethos from partner

- Group 1 Complete the personal best test to the best of their ability analyse and support. NB – Coach must have the record sheet available to monitor child performance.
- Coach monitors and records the results of the children as they reach the personal best and takes note of the child's number and records their designated lap on the record sheet
- When children reach their best and drop out of the challenge they will continue to complete the activity walking/jogging the laps and offering encouragement to the remaining participants

Cooling Down Activity

- Children move around in the safety zone completing a series of dynamic stretches e.g.
- Tall shapes, wide shapes, small shapes, floppy shapes.

Change Over

- The children then exchange with the remaining children (16-30) and the lesson is repeated
- Children 1-15 make their way back to the classroom. The designated adult who records the height and weight measurements of the children and record on relevant record sheet – children then also work out in their groups how much minutes of physical activity they do each week and how much is structured and un-structured?

Plenary

- Discuss feelings of participants throughout the challenge.
- What did they find difficult / easy? – discuss in small groups
- What would they do differently if they had another opportunity to complete the challenge, how would they make their personal performance better?

Appendix V: Supplementary Data

Table 12. 1 Fixed and interaction effects where 20mMSR raw scores were the dependent variable (from Thesis Chapter 7.0, Study 4)

Fixed or interaction effect	***F*** statistic	Degrees of freedom	***p*-value**
“Sex”	114	1, 1875	< 0.001
“Age-group”	50.7	5, 2077	< 0.001
“SES”	7.97	1, 15	< 0.001
“BMI z-score”	309	1, 2713	< 0.001
“Age-group * Sex”	2.04	5, 2123	0.070
“Age-group * SES”	3.21	5, 2080	0.007

Table 12. 2 Fixed and interaction effects where 20mMSR z-scores were the dependent variable (from Thesis Chapter 7.0, Study 4)

Fixed or interaction effect	***F*** statistic	Degrees of freedom	***p*-value**
“Sex”	0.68	1, 1876	0.409
“Age-group”	24.2	5, 2104	< 0.001
“SES”	8.8	1, 15	0.010
“BMI z-score”	308	1, 2681	< 0.001
“Age-group * Sex”	1.43	5, 2153	0.210
“Age-group * SES”	3.95	5, 2108	0.001